REPRODUCTIVE BIONOMICS OF THE WEDGE CLAM *MESODESMA GLABRATUM* (LAMARCK) ALONG THE SOUTH-EAST COAST OF INDIA

THESIS SUBMITTED TO THE MADURAI KAMARAJ UNIVERSITY

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D E C L A R A T I O N

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This is to certify that this thesis entitled, **"REPRODUCTIVE BIONOMICS OF THE WEDGE CLAM MESODESMA GLABRATUM (LAMARCK) ALONG THE SOUTH-EAST COAST OF INDIA"** submitted by Mr. A. CHELLAM, M.Sc., A.R.S., for the degree of Doctor of Philosophy in Zoology to the Madurai Kamaraj University, Madurai, is based on the original results of studies carried out by him under my guidance and supervision. This work has not formed the basis for any other degree.

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INTRODUCTION

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The intertidal zone, being a precarious marine habitat, is characterised by heavy wave action, and the possible erosion and accretion caused by climatic changes of land and sea. Therefore, the organisms living therein, have contrieved special adaptive features. The intertidal zone of the sandy beach can be classified into three zones. They are : (a) the supralittoral fringe (otherwise known as eulittoral fringe), (b) midlittoral zone (eulittoral zone) and (c) infralittoral fringe (sublittoral fringe) (Pichon, 1967). The organisms living in the supralittoral fringe are subjected to prolonged aerial exposure, and therefore specialised to survive, feed and reproduce under aerial conditions. The organisms that inhabit the midlittoral zone are experiencing about 50% of aquatic and aerial conditions, whereas those inhabiting the infralittoral fringe are truely aquatic, but well adapted to resist short periods of exposure to aerial conditions. The organisms of the supralittoral fringe are exposed to aquatic conditions only for a brief period during the spring tide. Conversely, the organisms of the infralittoral fringe are exposed to aerial conditions only for a short duration of few hours in each fortnight (Newell, 1979).

Alternatively, Dahl (1952) classified the sandy beaches into zonation according to the occurrences of various malacostracan crustaceans. According to him, an upper zone above the normal water level is called the subterrestrial fringe which is populated by crabs of the genus Ocypoda in tropics and talitrid amphipods in temperate regions. The midlittoral zone on the part of the shore that is wetted on every tide, is dominated by the isopods of the sub family Cirolanina, amphipods such as Bathyporeia and Urothoe, and also the polychaetes like Nephthys and Clycera. Besides these amphipods, isopods and polychaete worms, the midlittoral zone is occupied by a number of bivalve molluscs of the genus Cardium, Donax, Tellina, Macoma etc. The lower zone or sublittoral fringe is occupied by anomuran crabs in the tropics and amphipod crustaceans in the temperate regions.

The boundaries and the width of the inhabitable area of the beach are determined by the tidal range. Associated with the tide is the phenomenon of wave action which in turn determines the slope of the beach (Philip, 1972, Ahmad 1972) The mechanical force of the waves is mainly responsible for the erosion and accretion of sand on the beaches (Philip, 1972, Ahmad 1972). Again, the wave action and tide determine the submergence and emergence of the tidal zone as well as the degree of exposure of organisms to desiccation and other conditions of the beach. During the monsoon season, owing to severe erosion, the beach becomes very steep, reducing its expanse considerably. Extensive

erosion of the beach, owing to pounding wave action during the monsoon period is a characteristic phenomenon along the south west coast of India (Nair and Thampy, 1980).

Besides tides and waves, the particle size of the sand on the shore has definite relationship with the profile of the sandy shore; on shores with coarse deposits, the slope of the beach tends to be steep, whilst on shores composed of fine sand, the slope tends to be shallow, beach slope being a positive exponential function of particle size (Krumbein, 1944, Ahmad 1972). Further, exposed beaches tend to have better sorted sediments and less fine and subsieve material than sheltered beaches (Eleftheriou and Nicholson, 1975). McLachlan (1977 a,b) and Bascom (1954) have also found that particle size varies with the degree of turbulence, being coarsest at points of maximum turbulence and getting finer as wave action decreases. In general, the profile of a sandy beach is very unstable and fluctuating; these conditions being determined by the integrated effects of several variables such as waves, tides, winds and ground water (Nair and Thampy, 1980).

The sand grain size is perhaps the most obvious feature of the habitat that governs the amount of water that can remain within the minute spaces in between sand grains by way of capillary action. In graded or sorted sand, this is inversely proportional to the size of the grains. The capillary water

influences the distribution of animals in the High Water Neap Tide level and Mid-Tide level which are exposed for several hours. Because of the capillary action of sand, the water is raised to a considerable height above the sea level and this rise is highest in the finest sediments (Nair and Thampy, 1980).

It is well known that coarse deposits are mobile and may even move shoreward at several metres per day under exposed conditions, whereas, fine deposits are relatively static, only the surface being disturbed by wave action (Newell, 1979). For this reason the animals of sandy shores are active burrowers, but their burrows do not retain connection with the surface by means of a permanent tube. The organic content of the intertidal deposit also exerts an important influence on the nature and abundance of intertidal animals. The intertidal animals may not thrive well in beaches with high particulate organic carbon content in the sand. The organic carbon in the sand was derived mainly from the decaying of seaweeds, death and disintegration of animals, accumulation of large quantities of domestic wastes in the beach and the discharge of sewage into the sea. Particulate organic carbon is high in fine sand as it can retain more organic matter than coarse sand. The above mentioned physical factors determine the condition of the beach, and influence the organisms in their distribution pattern as well as their survival.

In general, the exposed sandy beaches, will have less population of macrofauna and abundant meiofauna. The macrofauna inhabiting the beach have evolved certain very specialised features such as quick burrowal in the shifting sand and ability to perform the normal activities in their burrowed state. In addition, these animals should also be prepared for exposure to aerial conditions. Nevertheless, the period of aerial existence may be overcome by vertical migration of the animals in accordance with the tidal conditions.

The exposure to wave and the tide action plays an important role in determining the density and the nature of the fauna. When the sand is exposed to heavy wave action, larger organisms may practically aviod it. Where it is fairly well protected, very rich population may inhabitate the zone, especially if the slope is gentle and the water remains high at low tide. While it is easy to burrow in, the sandy substratum prevents the animals from direct communication to be maintained with the surface, since the sides of the burrow will tend to collapse. To overcome this difficulty these animals exhibit various kinds of adaptations. Some polychaetes build tubes, some lamellibranchs have large siphons, while the Crustacea like Corystes have a special breathing tube which can be protruded above the surface of the sand while it remains burried (Stephen, 1952).

Like the wedge clams Donax spp, Mesodesma is one of the few bivalve molluscs that can successfully inhabit the intertidal sandy beaches in the islands and island-like conditions in the Gulf of Mannar. They are adapted to life on exposed shore and they do not occur on protected beaches or in shallow bays. These clams exhibit a high degree of specificity with regard to the nature of substratum and live exclusively in the saturated wash zone of the beach.

The vertical distribution of the clam Donax in terms of abundance, vary not only from beach to beach but also among species. Mori (1938) found that at high tide, D. semigranosus had its maximum density dispersed between the high and low water marks depending on the slope of the beach. Coe (1955) observed that the juveniles of D. gouldi are first found in a broad band near the mid water mark, but later they are scattered widely by the action of surf to lower and sometimes into water beyond the low tide limit. D. variabilis occupies the intertidal zone from the high tide (Edgren, 1959) to low tide mark (Pearse et al., 1942). D. variabilis and D. tumidis are found to occur in water of 0.3 to 1 m deep (Loesch, 1957). There have been reports on the occurrence of D. vittatus at a depth of 18 m (Yonge, 1949), and Parker (1963) described D. gracilis as being part of a benthic assemblage in depth from 11 to 26 m. Many others (Wade, 1964; Ansell, 1972; McLusky et al., 1975; McLachlan, 1980 and Mikkelsen, 1981) have reported on the distribution pattern of the genus Donax.

Individual population of this species has a unique ability to develop resurgences. From a minimum of few numbers to a maximum of 20,000/m^2 was estimated by Coe (1953, 1955). Ansell et al. (1972) have recorded a maximum density of 9000/m^2 in the beaches of south west India. On the sandy beaches at Sancole, Goa, the maximum number of D. spiculum recorded was 12040/m^2 (Achuthankutty, 1976).

Wade (1967) has reported that these clams have the ability to overcome the stresses of environment by their behavioural and morphological adaptations such as rapid burrowing, mobility on the surface and a high desiccation tolerance. D. denticulatus may completely burry itself within 2 seconds (Wade, 1967). During tidal migration, the clams are able to burry themselves into the sand before the backwash retreats. Furthermore, the wedge-shaped shell makes burrowing easier. Mobility through the surf water, resulting in tidal migrations, is made possible by the unusual quick movement of the siphons and foot. D. denticulatus is able to remain in dry sand for upto 3 days. This is a remarkable adaptation for the survival of clams especially when their migration is disturbed due to unfavourable environmental conditions (Wade, 1967).

Intertidal movements of the Donax species have been studied by many authors from different beaches (Aldrich, 1959; Ansell and Trevallion, 1969; Edgren, 1959; Jacobson, 1955;

Johnson, 1966 a,b; Mori, 1938, 1950; Pehlo, 1967; Stoll, 1937, 1938; Tiffany, 1971; Trueman, 1971; Turner and Belding, 1957; Wade, 1964, 1967; Irwin, 1973). Not all species of Donax make tidal migrations; for example, D. variabilis and D. gouldi stay in one position of the beach irrespective of the tidal amplitudes (Pehlo, 1967). Also, D. serra shows no tidal migration but exhibits a semilunar rhythm of movement from just above the mean tide level during springs to the low tide level during neap tides (McLachlan et al., 1979). It can be postulated that the clams undertake tidal migration to maintain their position in the saturated zone at all phases.

The size of the sand grains is an important factor since it determines the suitability of the substratum for the burrowing forms. The newly formed angular sand of volcanic islands is not a suitable substratum for the burrowing animals, as its angularity makes the penetration very difficult. Similarly, the beaches formed from calcareous deposits are also unsuitable for burrowing. Donax can neither maintain footing in coarse sand which tends to be loose, nor in fine sand which is firm and tight (Wade, 1967). But Mesodesma is an exception which prefer very coarse to coarser sand.

In general, all the beaches in which Donax exists are exposed to open sea. These beaches have a frequency of wave splashing once in every 6 to 8 seconds (Wade, 1967). The wave

action constantly stir the substratum and keep the sand well aerated and clean. The constant churning of the sand enables the organic detritus kept in suspension. Wade (1967) reports that although Donax can live only in clean sand, it requires a rich supply of organic matter as food which it procures from the surf water overlying the substratum.

The growth of the wedge clam belonging to the genus Donax, has been studied by a number of authors from different parts of the world such as Southern California (Coe, 1955), the Gulf of Mexico (Loesch, 1957), West Indies (Wade, 1964, 1967), Argentina (Penchaszadh and Oliver, 1975), South Africa (De villiers, 1975; McLachlan et al., 1979; McLachlan and Hanekom, 1979), France (Ansell and Lagardere, 1980) and Florida (Mikkelsen, 1981).

In India, growth studies have been made in D. cuneatus (Nayar, 1955), D. faba (Alagarswami, 1966), D. incarnatus and D. spiculum (Ansell et al., 1972), D. incarnatus (McLusky et al., 1975) and D. cunaeatus (Talikhedkar et al., 1976) inhabiting the east and west coasts of peninsular India. The above authors have found differences in the growth of the same species, inhabiting different beaches suggesting the influence of local environmental factors on the growth rate of these bivalve molluscs.

Growth studies made on different species of Donax in the Indian beaches have revealed several interesting features.

When the same species inhabits different beaches, the growth rate seems to differ markedly in different population, suggesting the influence of local environmental factors on the growth rate. As an example, D. cuneatus having a wide distribution in the east and west coast shows not only difference in the growth rate but also variation in the attainment of maximum size. On the east coast of India at Mandapam, D.cuneatus grows to a size of 13-14 mm in 11 months; 19 mm by the end of second years when they normally die (Nayar, 1955). This species inhabiting the west coast of India at Ratnagiri, showed a slightly higher growth rate, 13-14 mm at the end of one year, 21-22 mm at two years and 22-23 mm at about 2 years and 6 months. On the west coast of India at Goa, D. incarnatus grows to a maximum length of 21mm (McLusky et al., 1975) whereas it grows to a length of 24 mm at Cochin and 30 mm at Shertallai (Ansell et al., 1972).

Another interesting feature in the growth studies in the Indian species is the marked difference in the growth rate of different species inhabiting the same or different beaches.

Alagarswami (1966) observed a growth of 19.5 mm by the end of first year of life in D. faba from Mandapam in the east coast of India and 22.5 mm by the end of the second year of life, whereas D. cuneatus attains a size of 13-14 mm in the 11 months and 19 mm by the end of second year. At Shertallai, D. spiculum grows to a length of 15mm in about 6 months whereas D.incarnatus grows to a maximum length of 30 mm (Ansell et al., 1972).

In addition to this, different species of Donax inhabiting the different beaches of the tropical and temperate regions also exhibit differential growth rate as well as attainment of maximum size. All these suggest that, in addition to the inherent genetic characters of the different species extrinsic factors may also influence the growth rate and the attainment of maximum size. The life span of Donax species, in general, is greater in the temperate waters than the tropics.

Coe (1955) has found that the bean clam D. gouldi of Southern California attains a size of 12 mm at the end of one year, 18 mm at two years and 20 mm at about the end of three years, although most individuals perish after spawning at 1 - 1.5 years. In the Gulf of Mexico, D. variabilis grows to a length of about 20 mm at one year while D. tumida grows to 12-15 mm in a year, (Loesch, 1957). In Jamaica, D. denticulatus has a life span of about one year, growing to 14-18 mm depending on food availability (Wade, 1964). At Kaines Bay, the cold - temperate species D. vittatus differs from all the above warm water species in having relatively slow growth and long life span of 5-6 years (Ansell, 1972). On the South African shore the large warm temperate species D. serra, has relatively slow growth, but reaches more than 60 mm in length (de Villiers, 1975; Hanekom, 1975).

In general, the benthic as well as littoral marine invertebrates have a pelagic larval phase for dispersion in order

to expand their distributional range (Goshima, 1982). In a littoral species, whose adult phase is relatively sedentary, the settlement of young ones on the coast is an important phase in the life cycle. Again, the time of settlement of the young ones has a definite relationship with the reproductive cycle. The reproductive cycle of marine invertebrates may be continuous, annual, semiannual or biennial (Giese and Pearse, 1974). In general, the reproductive cycle of tropical marine invertebrates is of continuous or extended type. Several studies on the east and west coast of India reveal differences in the breeding pattern of invertebrates. The differences have been suggested to be due to variations in hydrographic conditions existing in the east and west coasts (Panikkar and Jayaraman, 1966). One of the major environmental factors influencing the Indian waters is the seasonal change in the salinity of the coastal waters. For example, the monsoonal rains are most effective during June to August in the west coast, whereas in the east coast the rainfall is intense during October - December months. The differences in the timing of monsoonal rains in the east and west coast is again reflected in the breeding activity (Varadarajan and Subramoniam, 1982 a).

The clam, D. cuneatus has a distinct annual reproductive cycle with prolonged spawning period extending from January to April at Mandapam (Nayar, 1955) and December - January to June at Madras (Rao, 1967), whereas at Ratnagiri of west coast

it was from October to January (Nagabhushanam and Talikhedkar, 1977). The clam, D. faba of Mandapam (east coast) has a spawning period extending from November to June with 2 peaks, one in November-December and the other in May-June (Algarswami, 1966). On the west coast of India, peak spawning occurs in D. incarnatus during April at Shertallai and in May at Cochin (Ansell et al., 1972). However, the peak spawning season in Goa for this species is from November to April according to McLusky et al.(1975).

During the south-east monsoon period from June - September, the coasts of Kerala, Konkan and Maharashtra receive more than 250 cm of rain, whereas during the north-west monsoon period (September-November) the east coast, excepting the southern most sector, receives considerable rain ranging from 75 to over 125 cm. Under its effect the salinity reduction recorded were 10%, at Cochin, 28%. at Shertallai and 22%. at Goa (KcLusky et al., 1975), 20.56%. at Ratnagiri (Nagabhushanam and Talikhedkar, 1977), 26%. at Madras and 27.47%. at Mandapam (Easterson and Mahadevan, 1980). Interestingly, the above studies on breeding season of Donax species on east and west coasts show that the reproductive activities are temporarily suspended during the peak monsoon season in the respective place.

Although the time of spat settlement in the various beaches have been recorded by several authors (Nayar, 1955; Alagarswami, 1966; Talikhedkar et al., 1976; Ansell et al., 1972

and McLusky et al., 1975), our understanding on the actual larval stages and their development in the open sea is meagre (Sastry, 1979). Laboratory studies on the development of the larvae of D. vittatus, however, gives some information on the larval development. The larva of D. vittatus grows through straight hinge stage and pediveliger stage before settling down on the substratum.

The factors influencing the larval dispersal and settlement may be the water current, force of the wind and the tide (Andrews, 1979). Therefore, the settlement of spat is not necessarily synchronous with the spawning season of a population, as the arrival of larvae from other population by way of currents and waves is possible (Sastry, 1979).

The reproductive biology of marine molluscs has been studied extensively during the last three decades. Though considerable work has been done on the gametogenesis of a few commercially important bivalve molluscs such as edible oysters, green mussels, brown mussels and scallops, our knowledge on the reproductive biology of the genus Mesodesma is very scanty.

Pelecypods exhibit wide variations in the expression of sexuality, ranging from strictly gonochoric species to functional hermaphroditic forms (Sastry, 1979). Like the species Donax, the Mesodesma are also strictly gonochoric (Fretter and Graham, 1964).

Along the 6100 km of coastline of India, molluscan shellfish are valuable fisheries used either as food or source of lime, as decorative shells or in industrial purposes. Twenty eight different species of bivalves and nearly sixty eight species of gastropods are commercially important. The fishermen have been exploiting marine aquatic organisms for centuries but the edible molluscan resources have remained as an augmentation to finfish landing rather than to have achieved a major industry status. It is essential to demonstrate that the molluscan fisheries can be done for food, employment and profit. Since the fishing of clams, oysters and mussels is at substenance level, the problem of overfishing does not arise. On the otherhand, there is scope for encouraging more fishermen to exploit these resources.

In Indian waters investigations on reproductive cycle have been made on a number of bivalve molluscs such as Crassostrea madrasensis (Rao, 1951, 1953, 1956; Stephen, 1980). C. gryphoides (Durve, 1965), Meretrix casta (Durve, 1964) and pearl oyster Pinctada fucata (Chellam, 1987). The gametogenic cycle and the biology of spawning have been extensively studied on other molluscan species of temperate waters such as Crassostrea virginica (Coe, 1938; Loosanoff, 1942; Loosanoff and Nomejko, 1951; Loosanoff and Davis, 1950, 1952 a,b), Ostrea edulis (Cole, 1941; Loosanoff, 1962; Davis and Ansell, 1962), Mya

arenaria (Coe and Turner, 1938; Pfitzenmeyer, 1962, 1965; Shaw, 1964, 1965; Ropes and Stickney, 1965) and Mercenaria mercenaria (Loosanoff, 1937 a, b, c).

In Saccostrea glomerata, the gonadal changes are cyclic, with well defined phases of gametogenesis, ripening and regression (Dinamani, 1974). Tranter (1958 a, b, c) in Australian Pearl oyster, Pinctada albina divides the cycle of gametogenesis into five stages of development and three stages of regression based on the method used by Kesteven (1945) for the Sydney rock oysters Crassostrea commercialis. Ropes and Stickney (1965) classified the gametogenesis of Mya arenaria into five arbitrary phases such as (1) inactive phase (2) active phase (3) ripe phase (4) partially spawned phase and (5) completely spent phase. Following this, Alagarswami (1966) divided the reproductive cycle of Donax faba into four phases namely (1) active phase (2) ripe phase (3) partially spawned phase and (4) spent and resting phase. Chellam (1987) has divided the gametogenic cycle into six phases in the Indian pearl oyster, Pinctada fucata namely developing, maturing, matured, partially spent, spent and resting. Similar classification of gametogenic cycle was also extended to other species of Donax such as D. cuneatus (Rao, 1967; Nagabhushanam and Talikhedkar, 1977) from the east and west coasts of India.

The wedge clam Mesodesma, like the various species of Donax almost exhibit a similar pattern of breeding activity with minor variations on the commencement and completion of gonadal activity. The clam, in general, shows prolonged spawning activity extending upto a period of six months followed by an equally protracted period of gonadal inactivity (resting period), before gonadal recrudescence commences again (Algarswami, 1966; Rao, 1967; Nagabhushanam and Talikhedkar, 1977).

For any study on the reproductive cycle, the determination of stage of first sexual maturity in different populations is a necessary prerequisite. In the wedge clam D. cuneatus such difference in the attainment of sexual maturity among different populations has been recorded (Nayar, 1955 and Talikhedkar et al., 1976). The implication is that the environmental factors influence not only the gametogenic cycle but also the attainment of first sexual maturity.

In Mytilus viridis, the older mussels appear to have a prolonged spawning period, commencing from July and lasting upto December, with peak spawning in September and November, whereas the younger individuals breed from January to April with a minor peak in February-March (Rao et al., 1975, 1976). It appears that lower salinity conditions bring about early maturity of gonads, whereas higher salinity hastens the onset of spawning.

In the Indian waters, the gonadal maturity as well as spawning of the bivalve molluscs have been shown to be under the influence of salinity changes. In Placuna placenta of Kakinada Bay, the gonad development occurs during the period of high salinity, whereas spawning begins with the dilution of sea water by monsoon rains (Sastry, 1955). Similarly for other species such as Meretrix casta and Martesia striata, such salinity dependent gonad maturity and spawning have been reported (Durve, 1964 and Balasubramanyan, 1970). However, in the shipworm, Nausitora hedleyi, breeding occurs during low salinity, and when the salinity is increased, the reproductive activities are inhibited (Nair and Saraswathy, 1970). According to Purchon (1968), the bivalve Egerina radiata (Donacidae) inhabits only relatively short lengths of certain South African rivers immediately above the main region of saltwater penetration. Possibly this species depends on increased salinity for breeding purposes.

The water temperature which varies from season to season may be also considered as another important abiotic factor influencing gametogenesis. This acts as a trigger for spawning in several marine invertebrates (Sastry, 1970). In temperate regions many workers have shown the existence of close relationship between the temperature fluctuation and the gonadal conditions in marine invertebrates. There, the rise of water temperature acts as the main stimulus for spawning activity in oysters (Nelson, 1928 a,b). However, in tropical waters the annual variation in

temperature which is kept to a minimum,has not had much influence over the spawning activity of Donax cuneatus (Nagabhushanam and Talikhedkar, 1977).

A more direct method to estimate the spawning season of bivalve molluscs is to monitor the appearance of larvae or the newly settled spat in the natural habitat (Pfitzenmeyer, 1962; Shaw, 1965). The appearance of new clams in the beach takes time since after spawning, the larvae have to grow through straight hinge stage, pediveliger stage in the pelagic phase before settling down and metamorphosing into spat (new clam) on a substratum. However, the duration of larval development varies among species and place of occurrence. Under controlled conditions, Loosanoff and Davis (1963), Walne (1964), Loosanoff (1971) and Turner and Johnson (1971) have determined the duration of larval development of certain pelecypods and found it to vary between six days (Mulinia lateralis) and forty days (Bankia fimbriatula).

Changes in the biochemical composition of whole body as well as individual organ systems during various months of the year have been taken into consideration in determining the annual reproductive cycle of marine invertebrates (Giese, 1959, 1969, 1976 and Giese and Pearse, 1974). However, such studies on molluscs have not shown any conclusive evidence on the yolk precursor materials to the maturing ovary. The eggs of marine

bivalve molluscs in general, are less yolky (de Jong-Brink et al., 1983) and hence the process of vitellogenesis may not constitute an extended event of oogenesis. Data in this regard are however, inadequate in lamellibranch molluscs.

From the foregoing review of literature on the reproductive ecology of marine molluscs especially the bivalves, it is clear that not much work has been done on the marine tropical wedge clam M. glabratum. Some literature is available on the Donax species, another wedge clam inhabiting the sandy beaches. This suggests that the environmental factors influence on this reproductive activities in both temperate and tropical conditions. Since these bivalves inhabit the intertidal beach, the beach profile might influence the population structure as well as the growth rate, which in turn would influence the reproductive output. In addition, biochemical evidence on the gamete formation is meagre. In view of the paucity of such information, the present study has been undertaken to investigate a rather wide spectrum of growth and reproductive activities of M. glabratum which inhabits the exposed sandy beaches of the islands of Gulf of Mannar and island-like condition along the coasts bordering the Gulf. More emphasis is given to the study of the physical conditions of the beach as well as their ecological implications on reproductive activity at population level. In addition, biochemical studies on gametogenesis has been made with reference to different stages in the gametogenic cycle. Intra-

organ changes of organic components as well as inter-organ transport of yolk precursor substances during maturation has also been studied, using both qualitative and quantitative biochemical methods. It may be pointed out here that our information on vitellogenesis, especially, the derivation of yolk precursor materials in the pelecypod marine molluscs is strikingly meagre.

The current line of thinking is towards promoting production of food resources of inshore animals. The acceptibility of molluscan meat as an item of diet has caught up amongst the Indian public and the present trend indicates great importance in utilizing molluscan meat as diet both exploiting natural beds and to evolve suitable technologies in producing them by culture practices. With this aim, a study was undertaken in the present Ph.D programme on this little known tropical marine wedge resource of Mesodesma glabratum of the Pandian Island (Lat N 8° 48′, Long E 78° 10′) (Fig. 1) where average Mean High Water Spring tide (MHWS) is 0.99m, Mean High Water Neap tide (MHWN) is 0.71m, Mean Low Water Spring tide (MLWS) is 0.55m and Mean Low Water Neap tide (MLWN) is 0.29m. The objectives of the investigation were :

(a) to study the ecology and distribution

(b) to find out age and growth

(c) to investigate on the reproductive biology

and (d) to evaluate the biochemical composition

Fig. 1. Map of the Islands of Gulf of Mannar. The inset figure shows Pandian Island and location of the sampling area.

1. Vantivu	2. Kasuwar	3. Karaichalli
4. Vilanguchalli	5. Upputanni	6. Puluvinichalli
7. Nallatanni	8. Anaipar	9. Valiamunai
10. Appa	11.Poovarasanpatti	12. Talairi
13. Valai	14.Mulli	15. Hare
16. Manoli	17.Manoliputti	18. Poomarichan
19. Pullivasal	20.Krusadi	21. Shingle

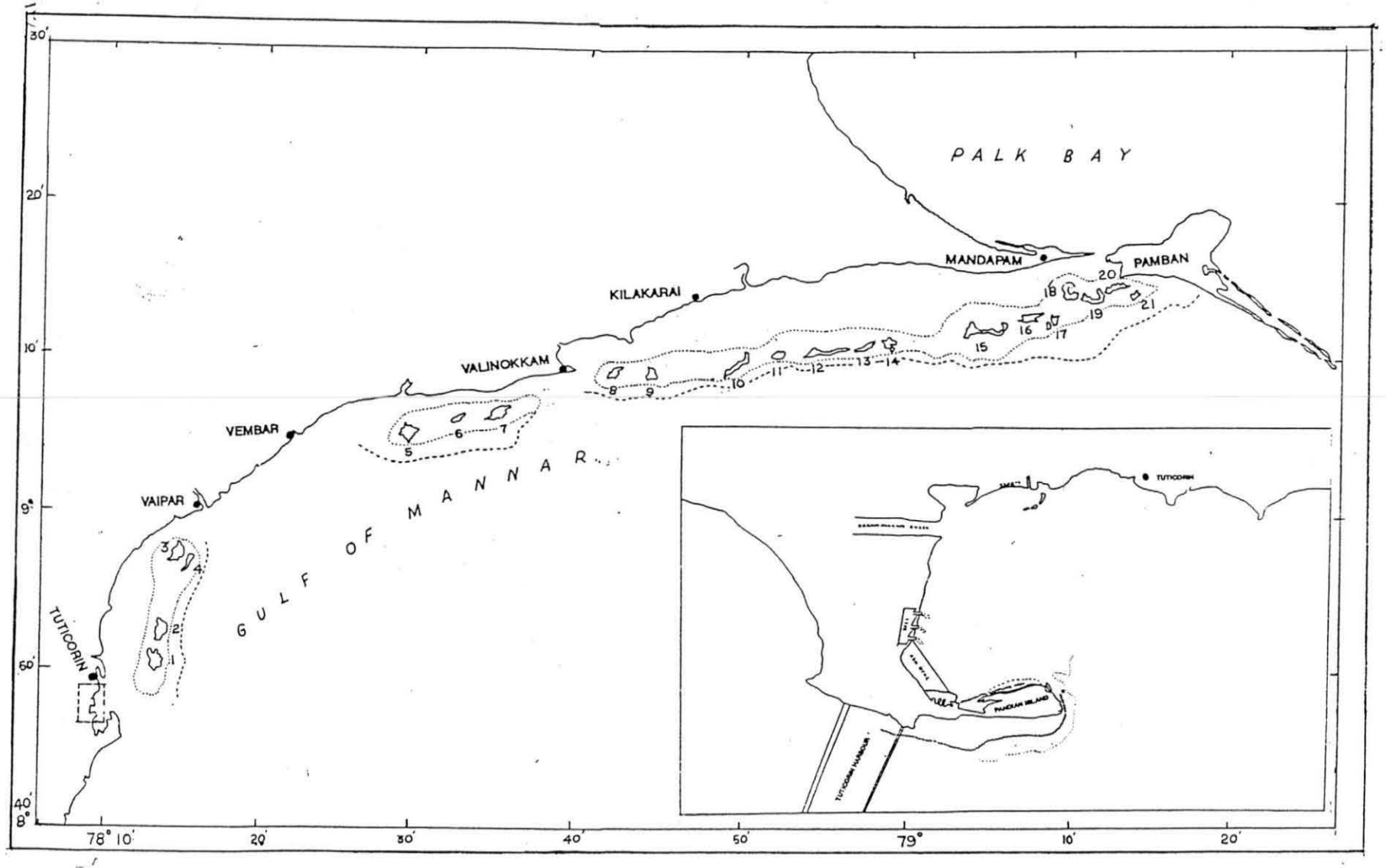

PALK BAY
GULF OF MANNAR
MANDAPAM
PAMBAN
KILAKARAI
VALINOKKAM
VEMBAR
VAIPAR
TUTICORIN
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
30'
20'
10'
9°
50'
40'
8°
78° 10'
20'
30'
40'
50'
79°
10'
20'

Fig.1

MATERIAL AND METHODS

2.1. Estimation of population density :

To determine the distribution and density of population, transect method of sampling was adopted. At each station, six transect lines were sampled. Transects A, B and C were at 10 m intervals and transects D, E and F were at 5 m apart (Fig. 2). On each fortnightly visit, in each transect line, an initial sample was collected at a point of maximum wave recession during low tide by driving a 28.2 cm diameter (0.0625 m^2 of surface area) stainless steel corer into the sand to a depth of 15 cm, below which depth the species had not been found to burrow. Additional samples were taken at 2 m intervals along the transect lines to the point of maximum wave advancement mark of the high tide. When the zone of clams was sighted, cores were taken at 1 m interval until the zone was thoroughly sampled. The sand samples were sieved through a 1 mm screen in the surf water and the clams retained on the above sieve were counted, to determine the population density.

2.1.1. Determination of mean particle size of sand :

To determine the mean particle size of the sand, sand samples were taken once a month in an identical manner, immediately adjacent to the specimen cores by driving a 6.0 cm diameter corer to a depth of 10cm, but was restricted to the zone

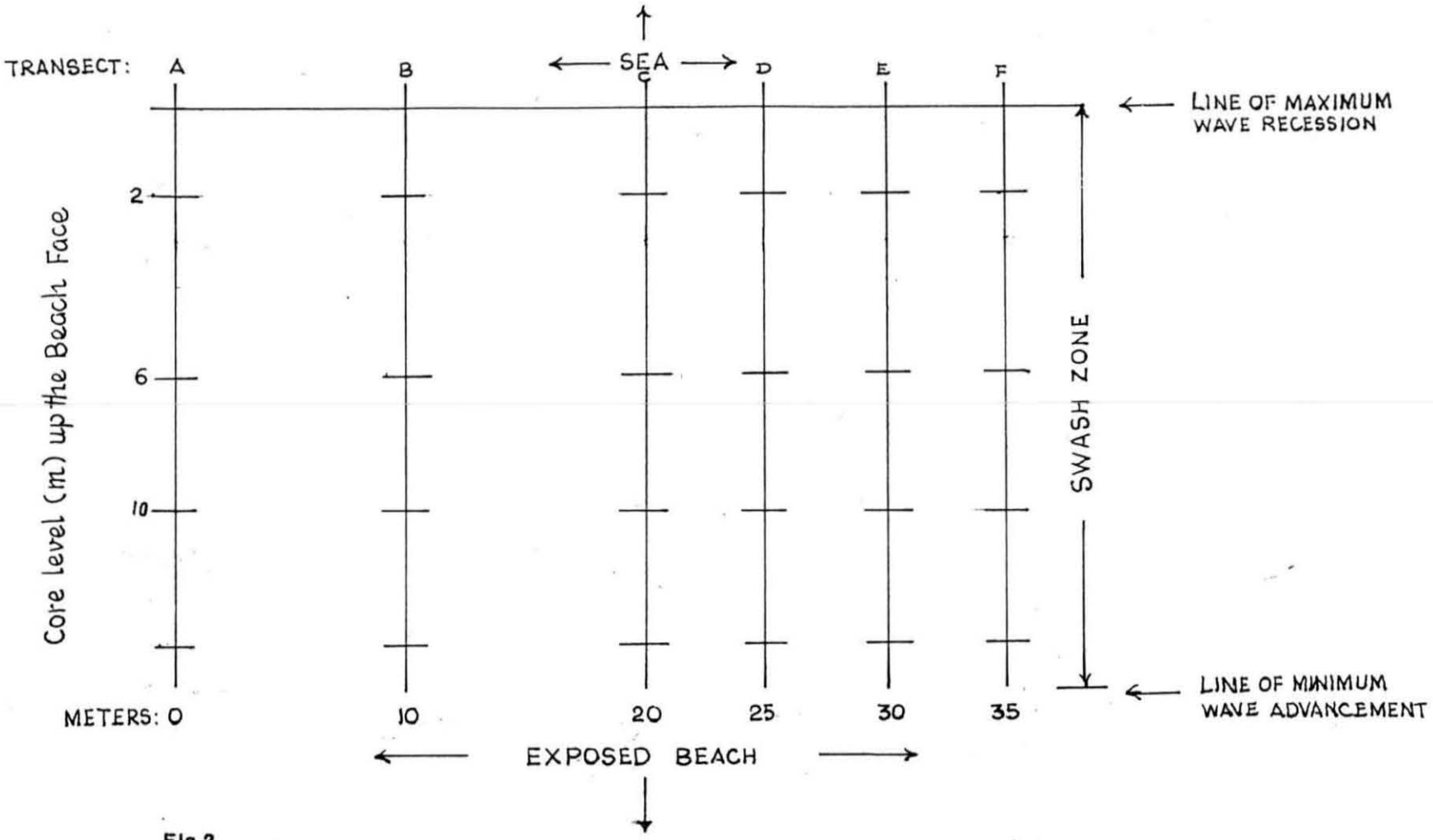

TRANSECT:
A
B
C
D
E
F
SEA
LINE OF MAXIMUM WAVE RECESSION
Core level (m.) up the Beach Face
2
6
10
SWASH ZONE
LINE OF MINIMUM WAVE ADVANCEMENT
METERS: 0
10
20
25
30
35
EXPOSED BEACH

Fig.2

in which the clams lived. While a small protein of the sand sample contained in the core was air dried and utilized for organic carbon estimation, the remaining portion was washed in fresh water, air and oven-dried and subjected to sieve analysis. Standard granulometric sieve analysis (Inman, 1952) was conducted on each sample.

A sieve analysis consists of shaking a sand sample through a stack of wire screens with pores of known size. The particle diameter is defined as the dimension of the size of the screen hole upon which the particle is retained.

250g of oven dried sand were weighed to the nearest 0.1g and was subjected to sifting through a series of sieves of the following pore sizes: 1 mm, 0.5 mm, 0.25 mm, 0.125 mm and 0.63 mm.

The weight of the sand retained in each sieve was noted and the percentage retained in each sieve was found out (Wt. of sand retained)/(total sand Wt.) X 100). The cumulative percentage retained on each sieve was calculated and then the percentage finer was found out. The data points obtained on the percentage finer was plotted against the grain size. From the curve thus obtained, the following were determined.

1. Uniformity coefficient	D_{60}/D_{10} which is an indication of the spread (or range) of grain sizes.
2. Uniform soil (poorly graded)	D_{60}/D_{10} less than 5
3. Uniform soil (well graded)	D_{60}/D_{10} greater than 5
4. Mean diameter	$1/2\,(D_{16} + D_{85})$
5. Median diameter	D_{50}
6. Effective diameter	D_{10} in which D denotes the grain size and the subscript denotes percentage finer.

2.1.2. Measuring the beach profile :

In each month, the slope of the beach was measured by triangulation (King, 1972) at 1 m interval from the seaward limit of the extreme high water spring tide to the base of the surf zone at the time of low tide for one year (January to December, 1991) while sampling was done.

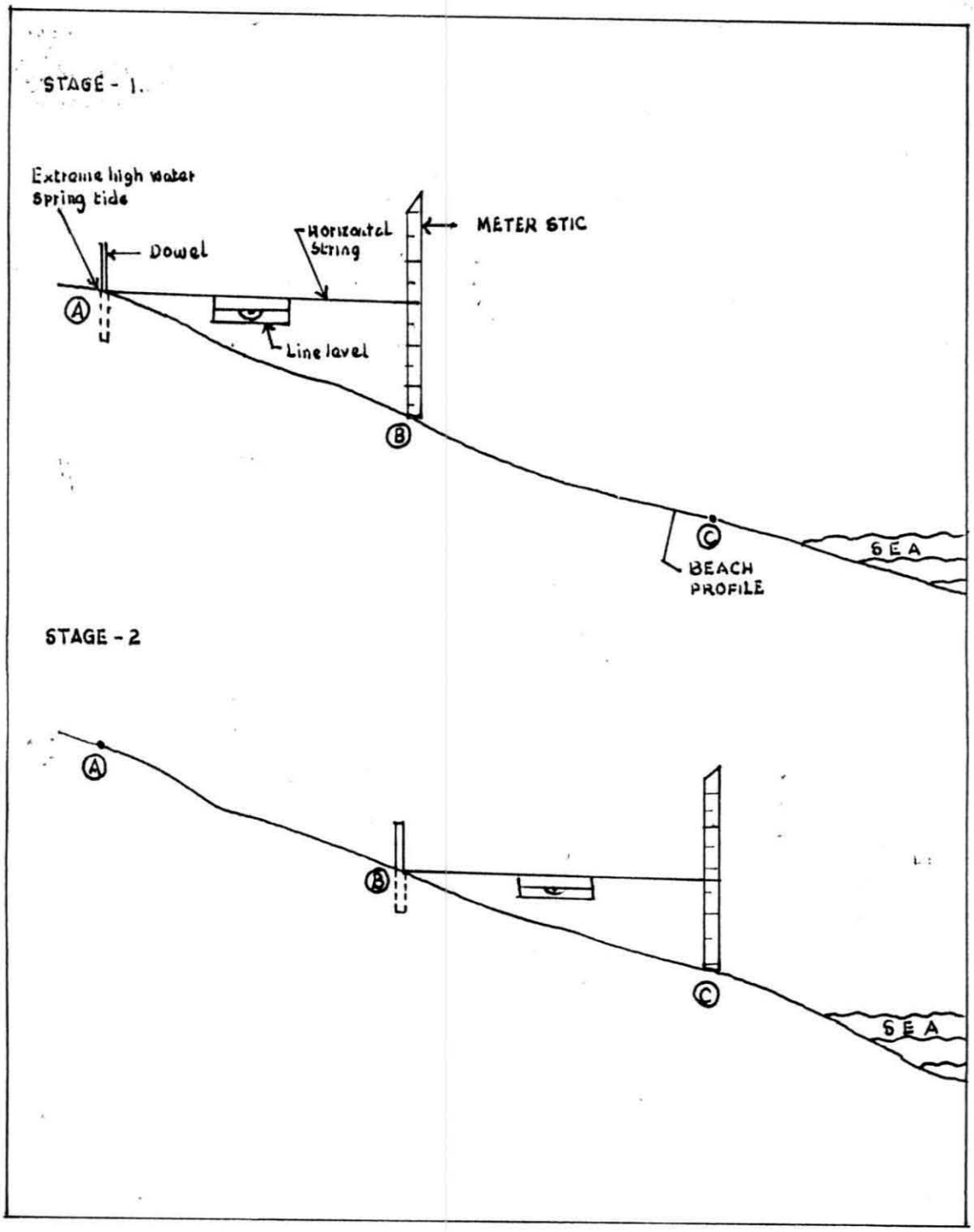
The tools required are : A string, a line level, a dowel to which the string is permanently attached and a meter stick upon which the other end of the string may slide vertically.

After tying the string securely to mid portion of the dowel and rather loosely to the meter stick, the length of string remaining between the two should be exactly 1 meter.

On arrival to the sampling site, the dowel was vertically driven into the sand, at the extreme high water spring tide mark of the beach (position A, in the Fig.3),until the attached string

Fig. 3. Diagram showing the process of measuring the beach profile by traingulation.

Fig.3


STAGE - 1.
Extreme high water
Spring tide
Dowel
Horizontal
String
METER STIC
A
Line level
B
C
SEA
BEACH
PROFILE
STAGE - 2
A
B
C
SEA

touched the sand surface. The meter stick was then used to stretch the string to its fullest extension, directly toward the water. The meter stick was then placed vertically onto the uppermost part of the sand surface (at position B), with the low end of the scale toward the sand. The tightly-stretched string was then elevated on the meter stick until the string was perfectly at level. The level of the string was maintained by using the line level (spirit level). A reading was taken at this level of the meter stick. The height between this point of the string down to the end of the meter stick gave the slope of the beach upto position (B). The process was then repeated by placing the dowel on the last position (B) and keeping the meter stick at position (C) with a distance of 1 m. The process was repeated until the entire profile was recorded from the extreme high water spring tide mark of the beach to the swash zone.

2.1.3. Estimation of organic carbon in sand :

The organic carbon content of the sand was estimated by the titration method of Walkley and Black (1934), which involves a chromic acid oxidation of the reducing fractions in the sample. Firstly, all the macro organisms from the sand sample were removed by hand. In order to remove the salts, the sand samples were thoroughly washed with distilled water on Buskner funnel filled with fine texture hardened filter paper. After drying the sample in hot air oven at 110 ^{o}C for 24 hours and then ground so that the sand could pass through a 0.5 mm sieve.

2g of sand sample was weighed and transferred into a 500 ml conical flask. 10 ml of potassium dichromate solution was added to it by means of a pipette followed by 20 ml of concentrated sulphuric acid. This mixture was shaken slowly for a minute or two, and then allowed to stand for 30 minutes. Then 170 ml of distilled water, 10 ml of concentrated orthophosphoric acid, 0.2 g sodium fluoride and 1 ml of diphenylamine indicator were added.

The contents were then titrated against 0.4 N ferrous ammonium sulphate solution till the contents attained a brilliant green colour. One or two blank determinations were also made using all reagents except the sand samples.

The results were calculated from the equation :

$$\% C = \frac{3.951}{g} \times \left(1 - \frac{T}{S}\right)$$

where

g = the sample weight in grams

s = ml ferrous solution for standardization of the blank

T = ml ferrous solution for the sample titration.

A recovery of about 75% was found and this was taken into account in the above formula for the calculation of organic carbon.

2.1.4. Measurement of temperature and salinity :

During each collection, interstitial and surf water temperature were recorded at the collection site at 07.00 hours, throughout the entire period of investigation. Similarly, salinity was also estimated by taking sea water sample from the collection site. The salinity determinations were done by the titration procedure as described in detail by Strickland and Parson (1965) using Normal Sea Water of Chlorinity, 19.381%, supplied by the Hydrographical Laboratories, Copenhagen as standard. Salinity was calculated from the chlorinity values by the formula.

Salinity %. = 0.03 + (1.805 x chlorinity)

2.2. Allometric relationship analysis :

In order to study the relationship between the length and other body measurements,the regression equation of the type $Y = a + bx$ was fitted by the least square technique (Snedecor and Cochran,1967). Length-weight relation was converted to logarithmic scale so as to fit an equation of linear form.

2.3. Determination of age and growth :

At each sampling, in addition to the specimen samples collected for determining the distribution and density of the population, on certain months, non-quantitative samples were also collected from all levels of the beach where Mesodesma were

present and utilized the samples for studying the size frequency distribution on the population. Soon after collection, the clams were brought to the laboratory and placed in fresh sea water for few hours to allow the clearance of sand and mud accumulated in their mantles. Then the clams were removed from the water, blotted dry and left for a short time in air to allow the shell surface to dry before being weighed. The whole weight of every specimen was determined to the nearest 0.01g. The length (the maximum distance along the long axis of the valves), the width (the maximum distance along the short axis of the valves) and the thickness (the maximum distance between the external surface of the two valves when they are closed) of every individual specimen was determined to the nearest 0.1 mm with vernier calipers (Fig.4).

The fortnightly samples were combined for each month to provide a monthly length frequency distribution. Among the different methods that are in vogue for studying the growth of bivalves, Peterson's method of length frequency analysis (modal length) has been found to be the most suitable method in determining the age and growth of M. glabratum . The modal lengths in the length frequency data were first plotted in the form of a scattered diagram against the coordinates of length starting from 0 upwards on the ordinates and time on the abcissa. The trend in the progression of the modes through time was then indicated by an eye-fitted line. The fitted line was extrapolated freehand with reference to the intermodal slopes so that it

intersects the time axis indicating the time of brood origin, the number of broods per year class, the periodicity of brood release, the growth of the brood since its origin through successive months and the approximate longevity of the clam.

Though certain rings are found on the shell, they have not been considered for studying the age and growth due to difficulties in ascertaining the periodicity of their formation. The initial experiments of 'mark and recapture'' techniques of growth measurement did not yield good result owing to constant movement of beach sands along with the clams and hence discontinued. Thus repeated sampling of the population to construct length frequency graphs was used.

2.4. Histological preparation :

For the purpose of histological studies, the clams were shucked and the soft bodies were taken out. The macrostructure of gonad, sex of the individual abundance of gametes and the general conditions were ascertained by examining fresh smears of gonad under microscope. Gonadal tissues were fixed in Bouin's fixative and 10% neutral buffered formaldehyde. It was then processed for paraffin embedding. The sections were cut a 6 um thickness and were stained in Ehrlich's haematoxylin and counterstained with eosin. In order to ascertain the size at which the clams attain the first sexual maturity, a series of young clams ranging from

15 mm in length onwards were collected in months of active gametogenesis and their gonad development were examined histologically.

2.5. Micrometric measurement of different stages of oocytes :

Increase in size of the oocytes is a function of oogenesis and hence micrometric measurements of oocytes in different stages of ovarian maturation can provide clue for classifying the oocytes. Since oocytes strongly deviate from a spherical shape, measurements were taken on the longest and shortest axes and both of them were added and divided by two. The oocytes of the size range upto 65.0 um were divided into 13 size-classes of 5 micron intervals.

2.6. Tissue weight study :

To study the seasonal changes in body weight, samples of M. glabratum in the shell length range of 20-37 mm were used. Samples were collected from each station at fortnightly intervals. Following collection, the clams were brought to the laboratory and placed in fresh seawater for a few hours to allow the clearance of sand that have accumulated in the mantle cavity. Then the clams were taken out of the water, blotted dry and then left for a short while in air to allow the shell surface to dry before being weighed. Depending upon the availability of clams, separate samples of 1-20 males, females and indeterminables were used to determine the wet and dry tissue weight and shell weight

to the nearest 0.01g. The length of every individual specimen was taken to the nearest 0.01 mm using vernier calipers. The clams were divided into narrow size groups by shell length. The shell was then opened by severing the adductor muscle and the soft tissues were removed, blotted to remove excess moisture and weighed, immediately in a preweighed crucible. The shell was also weighed after drying in air to a constant weight. After recording the sex of each specimen and wet weight of the tissue, the soft tissues were dried in an oven at 80 ^{o}C for 24-30 hours. The dried tissues were weighed till constant weight was obtained.

These data have been used to determine the relationships between shell length and total weight, total weight and wet tissue weight and also to calculate the wet and dry tissue weight for clam of each size group for each month as a percentage of the total weight.Since there were no significant differences over the size range examined in % wet and % dry tissue weights between different size groups, the individual determinations for all size groups for each month have been pooled to give a mean percentage for each month in determining the seasonal cycle in tissue weight.

2.7. Biochemical analysis :

In order to study the seasonal variation in the biochemical level of different body components, M. glabratum were collected on fortnightly intervals. The clams measuring

between 20 and 37 mm in length were taken for biochemical analysis. Biochemical analysis was made on males, females and indeterminables separately to determine carbohydrate, lipid, protein and ash for each body tissue such as the gonad,the hepatopancreas and the foot muscle.

For each analysis, the soft body tissue of 5 males, 5 females and 5 indeterminables were taken separately and pooled Since the gonad in the early stages of development was very small, a minimum of 5 clams had to be taken to obtain the required amount of dried tissue for each biochemical analysis. Other tissues such as hepatopancreas and foot muscle were also removed separately for biochemical determinations. After determining the weight of these three separate body tissues in a monopan electric balance, the tissue were kept in an oven at 80 C for 24-30 hours and reweighed till a constant weight was obtained. Then they were transferred and kept over calcium chloride in a desiccator. The dried materials were ground in a mortar to a fine homogenous powder. In each month, a minimum of 2 and a maximum of 10 analyses were carried out.

To study the biochemical changes of body components in relation to different gametogenic stages, further samples of M. glabratum the shell length ranging 20-37 mm were used. A sample of 20 each of males, females and indeterminable clams were shucked. After shucking, the maturity of the gonad was ascertained and individuals of the same gonadal condition were

grouped together . Then the gonad, the hepatopancreas and the foot muscle were separated from clams of the same sex with similar gonadal condition and transferred to separate crucibles of known weight. After determining the wet weight of each body component, the materials were dried to constant weight at 80 °C. Then they were transferred and kept over calcium chloride in a desiccator. The dried materials were ground in a mortar to fine powder. The water content was determined by subtracting the dry weight from the wet weight.

2.7.1. Quantitative determination of protein :

Folin-Ciocalteau method (Lowry et al., 1951) was employed to estimate the protein in the gonad, hepatopancreas and foot muscle.

Protein reacts with the Folin-Ciocalteau reagent to give a coloured complex. This colour is due to the reaction of carbamyl groups in the protein with the copper and potassium ions of the reagent. The colour is intensified by the reduction of phosphomolybdate by tyrosine and tryptophan present in the protein. The intensity of colour is thus related to the amount of protein in the sample (Lowry et al., 1951). 10 mg of dried and finely powdered tissues such as gonad, hepatopancreas and foot muscle from all reproductive stages (I-V) were precipitated with 2 ml of 10% trichloroacetic acid (TCA) and centrifuged at 3000 g. The supernatant was decanted and the precipitate was dissolved in

3 ml of 1 N sodium hydroxide (NaOH) and the three aliquots each with 1 ml were used as samples. Each aliquot was treated with 5 ml of alkaline copper solution for 10 minutes. As per Lowry et al. (1951) reagent A contains 2% sodium carbonate in 0.1 N NaOH. 0.5% copper sulphate in 1% sodium tartrate forms the reagent B. Reagent C was prepared afresh every time. Alkaline copper treated with protein was mixed well with the rapidly added Folin-Ciocalteau phenol reagent in the ratio of 1:1 with double distilled water. After 20 minutes the samples were read in a spectrophotometer at 500 nm along with blank and bovine serum albumin standard (0.1 mg of bovine serum albumin was prepared in 1 ml 1 N NaOH). The protein content of the tissue sample was expressed as mg protein/10 mg dry tissue.

2.7.2. Quantitative determination of total carbohydrate :

The presence of mono,di and polysaccharides in total free sugar were estimated by anthrone method (Roe, 1955).

Concentrated sulphuric acid in anthrone reagent hydrolyses di, tri and polysaccharides into monosaccharides and then dehydrated to furfural and its derivatives which react with phenolic compounds such as anthrone to produce a blue green coloured complex. The intensity of colour is proportional to the amount of saccharides present in the sample. Anthrone reagent was prepared by mixing 0.05% anthrone and 1% thiourea with 66% concentrated sulphuric acid. Standard stock glucose solution was prepared by dissolving 100 mg of glucose in 100 ml of saturated

benzoic acid. The working standard was prepared by dissolving 10 ml of stock solution with 90 ml of saturated benzoic acid. Thus 1 ml of working standard contains 0.1 mg of glucose. Blank was prepared by the addition of 0.5 ml glass distilled water and 5 ml of anthrone reagent.

To 10 mg of dried and powdered tissues such as gonad, hepatopancreas and foot muscle of M. glabratum in different stages of gonad maturation (I-V), 2 ml of 10% TCA was added and the tubes were twirled to bring about thorough mixing. The contents were centrifuged at 3000 g and the supernatant was used as the sample source. To each 0.5 ml of the supernatant, 5 ml of freshly prepared anthrone reagent was added quickly so that thorough mixing of the sample with anthrone was ensured. After the addition of anthrone in sample, blank and standard, the tubes were placed in a tap water bath for 5 minutes to bring the contents of each tube to the same temperature and then placed in a boiling water bath for 15 minutes. While heating, all the tubes were closed with glass marbles. After cooling to room temperature in a moderately illuminated or dark place all the tubes were read at 620 nm in a spectrophotometer. The total carbohydrate of the tissue sample was expressed as mg carbohydrate/10 mg dry tissue.

2.7.3. Quantitative determination of total lipids :

Total lipid content was estimated by the method of Folch et al. (1957), using chloroform and methanol as the solvent in the ratio of 2 : 1.

Methanol helps to break the protein bonds and free the lipid moieties of samples for extraction.

A weighed amount of dry tissue was homogenised with 10 ml of chloroform and Methanol mixture in the ratio of 2 : 1. This homogenate was poured into a 100 ml separating funnel and the biphasic layer was obtained by mixing the homogenate fast with 0.5 ml of 0.9% saline solution. The separated two phases were kept overnight at room temperature and the lower chloroform phase among with lipid extract was drained into a preweighed small test tube and the extract was evaporated and allowed to dry to constant weight. The difference of weight gives the weight of the total lipid present in the sample and was expressed as mg lipid/10 mg dry tissue.

2.7.4. Determination of ash :

Ash determinations were carried out by incinerating the tissues in a muffle furnace at 500 ^{o}C for 12 hours.

2.7.5. Estimation of calorific content :

To obtain calorific values for each body component (K cal/g dry weight) in each individual and for their seasonal changes in calorific content, the biochemical data were converted by the use of appropriate calorific factors of 4.1 for carbohydrate, 9.45 for lipid and 5.65 for protein (Ansell et al., 1973).

RESULTS

3.1. SYSTEMATICS

Class	: Bivalvia Linne, 1758
Subclass	: Heterodonta Neumayr, 1884
Order	: Veneroida H & A Adams, 1856
Super family	: Mactracea Lamarck 1809
Family	: Mesodesmatidae Gray 1839
Sub family	: Mesodesmatinae Gray 1840
Genus	: Mesodesma Deshayes, 1832
Species	: Mesodesma glabratum (Lamarck)

Identifying characters

The shell is thick, solid and more or less flattened and the two valves are compactly pressed together. The shell is somewhat triangular in outline with a narrow more or less pointed hind end and a comparatively broad and rounded front margin. Surface of the shell is strongly and concentrically striated. The striae of the shell are more or less pronounced towards the ventral and posterior margins. When the two values are placed together in close position, the portion behind the umbo form a well defined, flattened area, traversed longitudinally by the strong terminal parts of the concentric striae. The umbones are small and there is no lunule. The outer surface is whitish towards the umbo and yellowish brown towards the margin, the latter colour is mainly due to the presence of remnants of the horny, brown periostracum which covers the shell in the fresh condition (Satyamurti,1956).

The hinge bears two thick cardinal teeth in each valve with a deep triangular pit in between them, in which the ligament is embedded. A more or less anterior lateral tooth is also present. The pallial sinus is small. The inner surface is smooth, glossy and white (Plate 1).

3.2. ECOLOGY OF THE STUDY AREA :

3.2.1. Description of the study area :

The Gulf of Mannar is relatively a sheltered area. The position of Ceylon and the layout of Gulf of Mannar here is such that the sea and the coast is comparatively protected and the south-west and north-east monsoons and currents called the N.E. and S.W. monsoon drift do not enter the Palk Straight and Gulf of Mannar. This might be the cause of the origin of offshore islands in the area. These islands are low, alluvial or sandy, non-rocky and are situated at an average distance of 7 km from shore. They are narrow with east-west axis and some of them have rocky coast (Ahmad,1972).

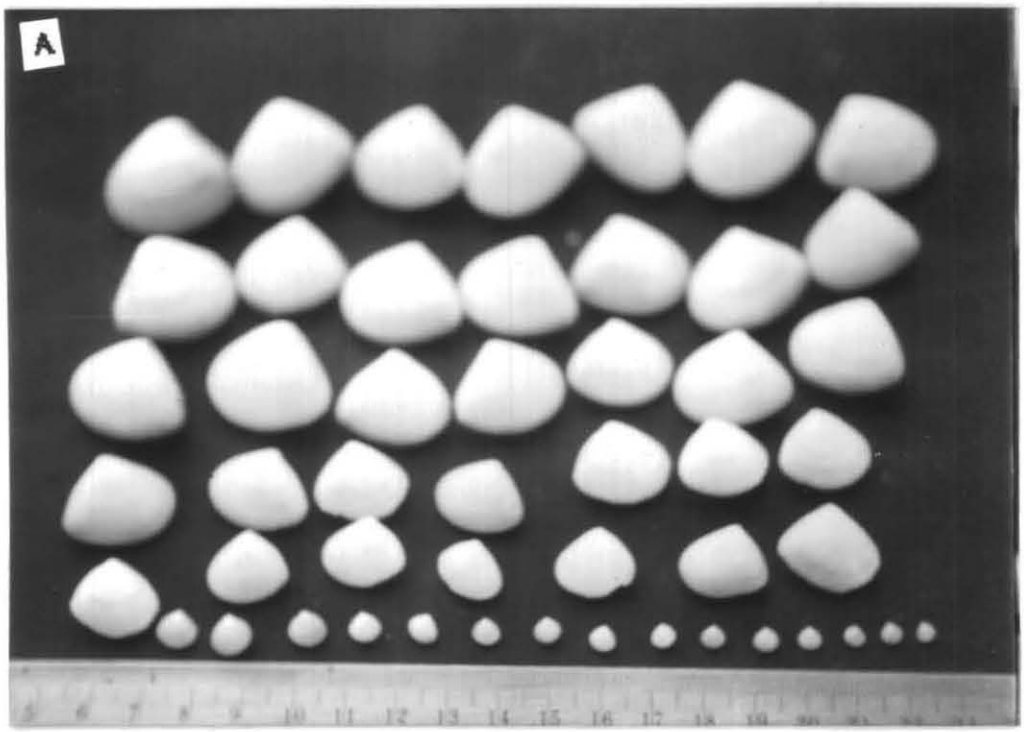
The beach sand of these islands is coarser than mud and practically major part of the sand building the beaches is derived from the sea floor. The chief agent that leads to the deposition of the beach is sea waves which is responsible for the roundness produced in the sediments. A very major role is played by currents. The predominant material of the beach is the sand. The beach material may range in grade from boulder through

Plate 1.

A. The wedge clam Mesodesma glabratum showing different sizes ranging from 1mm to 37mm.

B. A cluster of (medium sized) Mesodesma glabratum

Plate 1



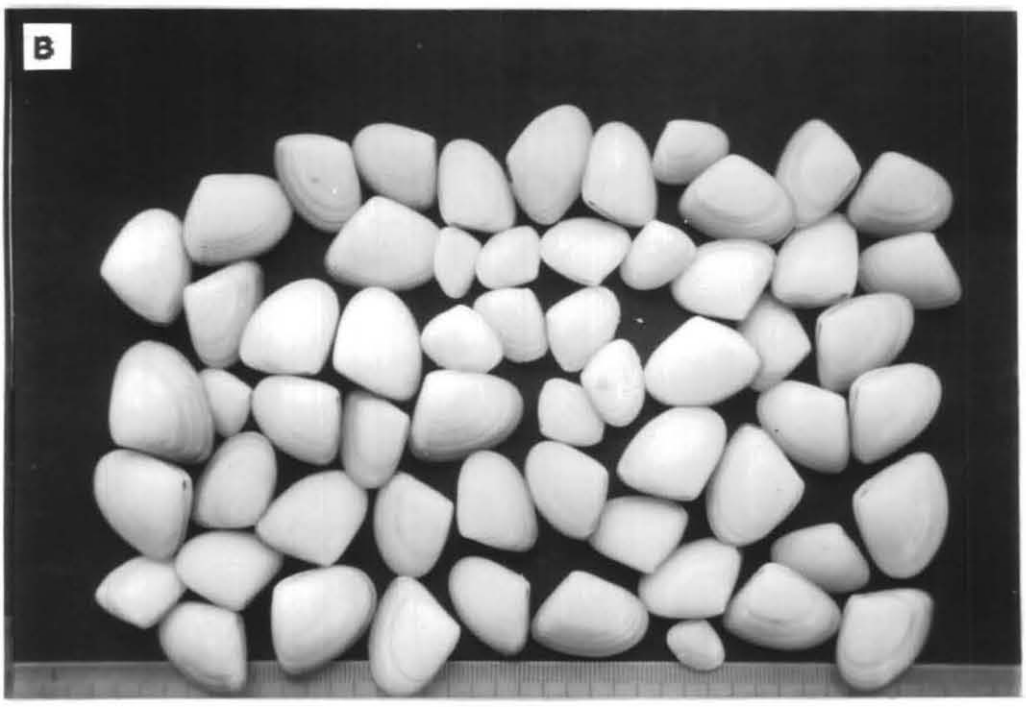
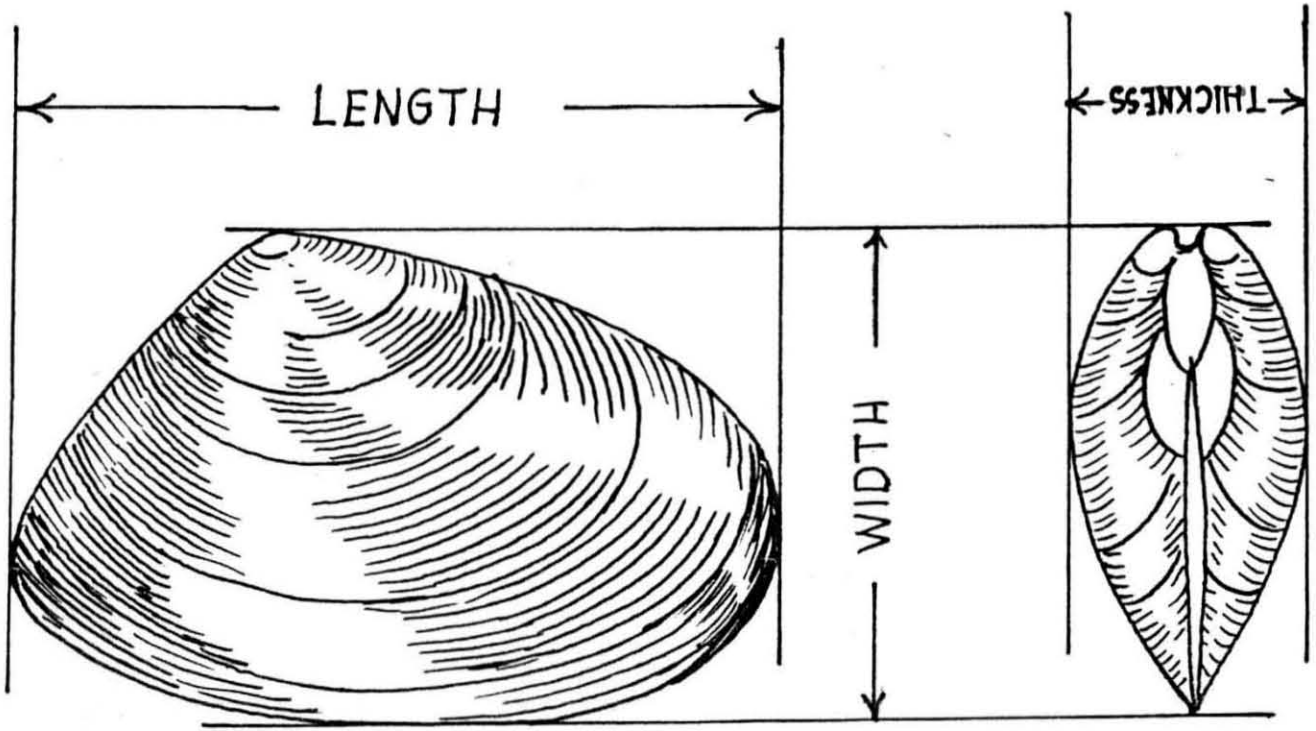


Fig. 4. Shell dimensions of Mesodesma glabratum referred in the text.

Fig.4



shingles, pebbles and sand to silt. The debris on the beach is generally heterogenous. It is sorted and graded more completely in the shore that is well exposed to the sea. Shingle (fragments of 25 to 500 mm diameter) is deposited mostly on the backshore where waves under the tides and storms are operative whereas sand is predominant on the foreshore.

The essential characters of a beach are : (i) upper beach located in the backshore zone and generally of coarser material and (ii) lower beach in the foreshore zone. The slope and grade of the sediments change rather markedly at the junction of the upper and lower beach (Ahamad, 1972).

The wedge clam, Mesodesma glabratum are specifically known to occur in the islands of Gulf of Mannar. In order to find out their occurrence on beaches of the mainland, a preliminary survey was carried out from Punnakkayal, a coastal village 30 km south of Tuticorin to Valinokkam which is situated 100 km north of Tuticorin. It is found from the survey that these clams do never inhabitate the sand shore where the sand particle is small and hard with more of silt. They never prefer mud or muddy sand and or places nearer to river mouths and sewages of any kind.

A population of this wedge clam was struck at Vellapatty, a sandy coast with loose sand and away from river flow and human pollution. Another population was located at the bay and sea side shores of the Pandian Thivu, an island till the

construction of the harbour and lately thermal station and was sparingly connected to the mainland. Populations of this clam in varying densities are available in three islands of Tuticorin Group (Vanthivu, Kasuwar and Karaichalli), three islands in the Vembar Group (Uppithanni, Puzhuvannichalli and Nallathanni) seven islands in the Kilakarai Group (Anaipar, Valiamunai, Poovarasanpatti, Appa, Talaiari, Valai and Mulli) and seven islands in the Mandapam Group (Musal, Manoli, Manolipatti, Poomarichan, Pullivasal, Krusadai and Shingle) (Rajan and Rajapandian, 1987). For the sake of convenience of regular observation and sampling, the clam population of the Pandian island which is connected to Tuticorin by a road was selected for the present study (Fig. 1).

3.2.2. Beach profile :

The profile of a beach can be divided as follows:
Type (i) : A foreshore section whose gradient decreases seaward. Type (ii) Have a foreshore and backshore, the backshore section consisting of a bern or a practically horizontal beach terrace, the foreshore section being similar in profile to that in the first type. Type (iii) May or may not have a backshore marked by a bern but it has a foreshore with a low-tide terrace (Ahmad, 1972). The beach profile of the study area belonged to the last type where a low tide terrace was formed whenever there was high winds and waves.

3.2.3. Beach slope :

The slope of the beach is related to the size of sediment forming the beach. If the diameter of the beach fragments vary from 256 mm to 64 mm in size, the slope of the beach will be at 24^{o} angle. If the size of the fragments vary from 64 mm to 2 mm (pebbles and granules), the slope will have an angle at $11^{o}-17^{o}$. If the sediments vary in size from 2 mm to 0.5 mm (very coarse and coarse sand), than the slope is formed at an angle of $7^{o}-9^{o}$. When the size of the sediments vary from 0.5 mm to 0.25 mm (coarse and medium sand), the slope will be at an angle of $5^{o}-7^{o}$. In the case of sediments whose grain size range from 0.25 mm to 0.12 mm (medium and fine sand), them the slope of the beach will be at an angle of $3^{o}-5^{o}$. When the beach is formed with very fine sand of the size 0.12mm to 0.06 mm, the slope of the beach will be at 1^{o} (Ahamad, 1972).

In the study area the sediments forming the beach consisted of pebbles and granules to very coarse to coarse sand (Table 1). The constituent sediments and their deposition on the beach was influenced by the prevailing waves and currents.

The beach slope of the study areas exhibited a mean drop ranging from 2.0 cm/m to 4.0 cm/m. The erosion and change of slope of the beach was due to strong winds, powerful breakers and their pounding action during the monsoon. The intertidal expanse was the maximum at 14 m.

3.2.4. Sand particle size :

The variations in the mean particle size of the sand was measured for a period of one year from January - December 1991 (Table 1). The sand samples taken at the three core areas (1,2 & 3) were mixed thoroughly and a subsample of 500 g was taken and analysed. The analysis indicated that the sands were predominantly with ununiform sized fragments (D60/D10 was more than 5). The median particle size (D50) ranged between 0.7 mm in January and 50.0 mm in September. The uniformity coefficient (D60/D10) ie, the spread of the grain sizes ranged between 2.57 to 400.00. The ununiformity of the sand particles in the beach was largely due to the abundance of large shell and coral fragments.

3.2.5. Sand organic carbon :

The monthly variations in the organic content of sand is given in Table 2. The organic carbon content of the sand varied between 360 µg/g (May, 1992) and 750 µg/g (Feb.1992). The mean annual range of organic carbon in sand was 390 µg/g. The organic carbon was low in the beach sediment because this beach is almost away from the river mouth and other sewages.

3.2.6. Temperature :

The temperature recorded at the study area during the study period is given in Table 3 and Fig. 5. The monthly mean

Table 1. Variations of mean particle size and uniformity coefficient of sand at core levels at the inter tidal zone of the beach during January - December 1991.

Year/ Month	Percentage retention of sand at seives with mesh					Median particle size (mm)	Uniformity coefficient
	1mm	0.5mm	0.25mm	0.150mm	0.75 mm		
1991							
Jan	28.06	36.60	24.85	10.16	0.33	0.70	2.57
Feb	33.25	30.42	26.43	9.47	0.43	0.74	3.92
Mar	46.60	28.00	16.12	8.83	0.45	1.10	18.79
Apr	42.52	28.53	20.00	8.45	0.50	0.98	14.55
May	51.82	25.78	12.54	9.14	0.72	4.00	25.33
Jun	59.99	19.00	11.47	8.99	0.64	8.50	187.88
Jul	62.20	16.20	12.04	9.05	0.51	25.0	400.00
Aug	57.40	20.27	12.65	9.25	0.43	8.30	400.55
Sep	63.31	17.71	10.70	7.68	0.60	50.00	-
Oct	65.20	18.03	9.37	6.82	0.58	-	-
Nov	71.30	16.00	8.84	3.32	0.54	-	-
Dec	47.48	28.60	10.06	13.65	0.21	2.00	187.50
Mean	52.43	23.76	14.58	8.73	0.50	-	-

Table 2. Particulate organic carbon content in sand with core level and transects at the intertidal zo

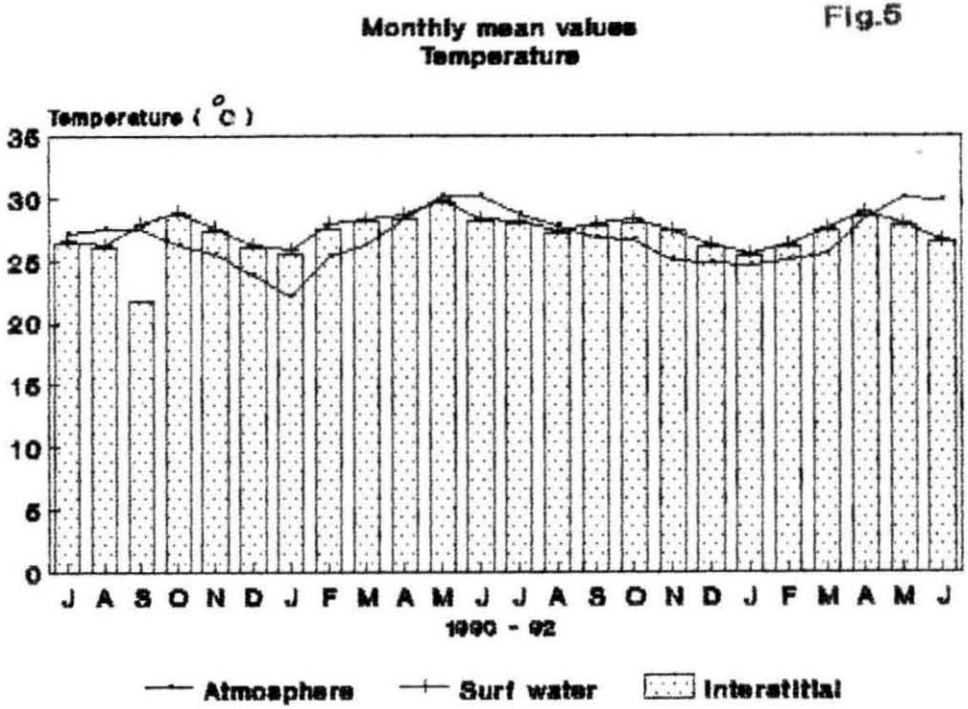
Year/month	Core area at m up in the beach face (in µg/g)			Parliculate organic content in sand in transects (in µg/g)					
	2 (m)	6 (m)	10 (m)	A	B	C	D	E	F
1990 July	610	690	740	690	680	690	670	650	700
August	680	720	610	690	660	670	680	630	690
September	580	660	740	670	630	680	660	620	700
October	520	680	750	620	650	680	670	640	700
November	580	640	730	630	640	650	670	650	660
December	710	730	670	720	690	710	720	700	680
1991 January	590	730	670	600	620	620	610	580	630
February	480	560	610	530	570	550	550	540	530
March	450	510	540	500	490	500	510	500	500
April	740	700	690	720	700	710	700	710	720
May	500	490	450	490	480	490	470	490	460
June	430	470	450	440	440	460	440	460	460
July	360	380	400	380	390	370	380	390	370
August	400	440	0	410	430	420	400	430	430
September	370	380	390	380	375	380	385	380	380
October	380	370	360	370	375	370	365	370	370
November	370	370	360	370	370	365	365	360	370
December	500	520	450	500	490	510	470	480	490
1992 January	620	560	530	550	570	590	560	580	570
February	750	740	700	740	720	730	730	720	740
March	480	530	520	510	500	520	490	520	520
April	450	490	530	470	480	510	490	490	500
May	390	370	360	370	370	365	365	375	375
June	380	380	370	375	375	370	380	380	380
Mean	509	532	538	522	524	531	520	519	532
S.D	123.3	129.1	138.5	127.7	120.2	128.3	127.2	118.2	130.8

Table 3. Monthly mean values of temperature and salinity at the intertidal zone during July 1990 - June 1992.

Year/ month	Temperature °C			Salinity ‰.	
	Atmospheric	Surf water	Interstitial water	Surf water	Interstitial water
1990					
Jul	27.2	26.6	26.4	34.13	33.81
Aug	27.5	26.3	26.1	33.45	33.03
Sep	27.5	27.9	21.8	32.72	32.43
Oct	26.3	28.8	28.7	27.76	27.66
Nov	25.5	27.5	27.3	28.48	28.88
Dec	23.8	26.3	26.1	29.88	29.83
1991					
Jan	22.1	25.8	25.6	30.75	30.40
Feb	25.4	27.9	27.5	31.58	31.31
Mar	26.3	28.4	28.1	33.17	33.03
Apr	28.3	28.7	28.3	34.14	33.97
May	30.2	29.9	29.6	34.87	34.65
Jun	30.2	28.4	28.2	34.36	34.26
Jul	28.7	28.2	27.9	34.16	34.10
Aug	27.7	27.4	27.2	33.73	33.54
Sep	26.8	28.0	27.7	32.23	32.13
Oct	26.6	28.3	28.0	27.42	27.34
Nov	25.0	27.4	27.3	27.01	26.87
Dec	24.7	26.2	26.1	24.40	24.29
1992					
Jan	24.5	25.5	25.4	29.15	29.07
Feb	24.9	26.2	26.0	29.36	29.24
Mar	25.6	27.6	27.3	32.98	32.79
Apr	28.4	28.8	28.5	33.51	33.27
May	30.0	28.0	27.8	33.95	33.80
Jun	29.9	26.6	26.4	34.34	34.24
Mean	26.6	27.5	27.1	31.6	31.4
S.D	2.3	1.1	1.6	2.9	2.9

Fig. 5. Monthly variations in the mean values of temperature from July 1990 to June 1992.

Fig.5


Monthly mean values
Temperature
Temperature (°C)
35
30
25
20
15
10
5
0
J A S O N D J F M A M J J A S O N D J F M A M J
1990 - 92
Atmosphere
Surf water
Interstitial

atmospheric temperature, surf water temperature and interstitial water temperature did not vary much over the period. The monthly mean atmospheric temperature fluctuated between 22.1 °C (January, 1991) and 30.2 °C (May,1991); surf water temperature between 25.5 °C (January, 1992) and 29.9 °C (May, 1991) and the interstitial water temperature fluctuated between 25.4 °C in January, 1992 and 29.6 °C in May, 1991. The mean annual range of variation being 8.1 °C in atmospheric temperature, 4.4 °C in surf water temperature and 4.2 °C in interstitial water temperature.

The pattern of oscillation seen in the atmospheric temperature was a unimodal one with one peak and one depression corresponding to the months of May and December - January. The pattern of oscillation seen in the surf water temperature and interstitial water temperature was a bimodal one with two peaks and two depressions corresponding to the months of April-May, October and August and December-January. The temperature changes during the sampling period did not seem to affect or fluctuate in the size of population.

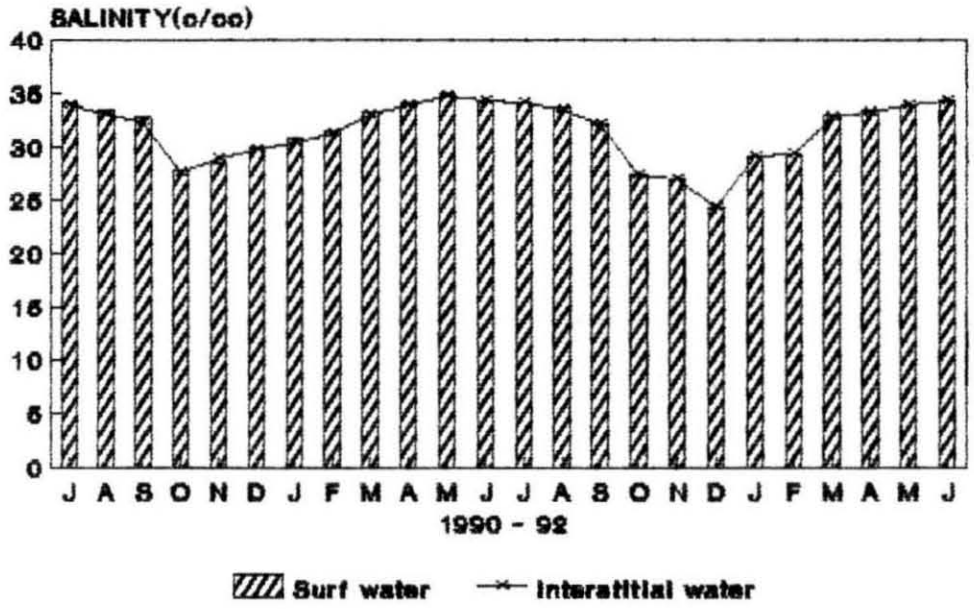
3.2.7. Salinity :

The salinity data recorded for the two year period is given is Table 3 Fig.6. The coincidence between the salinities of surf water and the interstitial water was continuous, although the surf water was slightly over -saline than the interstitial water. Unlike temperature, the salinity showed monocyclic

Fig. 6. Monthly variations in the mean values of salinity from July 1990 to June 1992.

Monthly mean values
SALINITY

Fig.6



condition in its annual variation. The salinity was high during the period of south-west monsoon (May-August) and low during the period of north-east monsoon (October-January). The monthly mean values of surf water and interstitial water salinities ranged between 24.40‰ (December 1991) and 34.87‰ (May, 1991) and 24.28‰ (Dec.1991) and 34.65‰ (May, 1991) respectively. The mean annual range of variation was 10.47‰ in surf water salinity and 10.37‰ in interstitial water salinity. The pattern of oscillation seen in the surf and interstitial water salinities was unimodal with one peak and one depression corresponding to the months of May-June and November - December.

3.3. OBSERVATION ON THE ECOLOGY OF MESODESMA GLABRATUM :

3.3.1. Life habitat :

These wedge clams are adapted to the life on exposed sandy shores of the islands of Gulf of Mannar and a very few pockets on the mainland where the island-like conditions exist. They never occur in protected beaches or in shallow bays. They live burried mostly in the sand in the mid tide level of these beaches, with their siphons extruded to the surface and feet extended as anchors. Occasionally the clams are flushed from the sand by the waves and are carried in the uprush but as the backwash retreats, they are washed down. However, by extending their siphons and feet to act as a breaking device, they prevent

themselves being washed down as far as the original levels. This mode of movement was noted for the Donax sp. also (Wade, 1967). When the wave subsides,the clams begin to flatten their feet against the substratum and insert them into the sand while the siphons are withdrawn into the shell. The clams then rapidly rock back and forth and get burried into the sand by a combination of their digging movement and scourging of sand. Individual population of the species has the unique ability to develop resurgences and are subjected to sudden and devastating population crashes in Donax sp. (Johnson, 1957). The same trend in the populations of M. glabratum in the study area was also observed.

3.3.2. Distribution :

The wedge clam of the genera Mesodesma are typical inhabitants of exposed sandy beaches and their distribution is restricted to island conditions in the Gulf of Mannar. The islands of the Gulf of Mannar are made up of coralline outgrowths and the beaches are mainly coarse sandy with shell and coral fragments combined with sand of different grades which are washed ashore by the action of the waves and currents. The site of study, the Pandian Thivu (Pandian Island) was till recently an island and because of the developmental activities of the harbour it was connected to the mainland by a road. These clams are mainly inhabiting the island beaches and a few pockets on the

mainland bordering Tuticorin (Vellapatty) (Fig.1). Two species, Mesodesma glabratum(Lamark) and M. trigona are reported from the islands of Gulf of Mannar (Sathyamurthy). The only other two species of the genera Mesodesma ,reported from other part of the world are M. arctatum (Greenland) and M. deauratum (Canada). No information is available about these species except their occurrence. The other wedge clam of the genera Donax also co-exist along with the Mesodesma but in less numbers.

The vertical distribution pattern of the wedge clam Donax sp. was found to differ from species to species and from season to season depending on the changing physical characteristics of the beach during tidal cycle, because these animals exhibit some form of tidal movement. Authors like Jacobson (1955), Edgren (1959), Wade (1969, 1967) and Ansell and Trevellion (1969) have reported on the intertidal movement of Donax spp. and speculated the stimulus for such migration. The non-migratory nature of these species in some beaches has been found out by Edgren (1959) and Mikkelson (1981). Without tidal migration a similar rhythm of movement from just above mean tide level during spring tides to the low tide level during neap tides was observed in the large wedge clam, D. serra by McLachlen et.al. (1979).

During the period from July 1990 through June 1992, a total of 2951 clams of M. glabratum were collected. The average

density per linear meter of the bach was found to vary from 7.75 (July 1990) to 25.42 (June, 1991). There was very little difference in numbers between the transacts. The mean density of the population per square meter varied from month to month. The highest density was during the month of June 1991 (41.7 m^{-2}) and the lowest being during the month of November 1990 and September 1991 (8.0/m^{-2}).

The observations on the vertical distribution of the population of M. glabratum showed that the entire population was found to occupy relatively a stable zone in the beach, viz. the midwater mark (Table 4). Under normal conditions, the clams were found not to live in the high water mark as well as in the low water mark, although occasionally, during rough seas, they were scattered so high on the beach or carried into water to lower levels. From the maximum recession point, M. glabratum began to appear shorewardly in cores at about 5-10 m from the wave recession point. After first sighting, the density of the clams increased rapidly in the subsequent cores and decreased to nil in the cores at the high water mark. It may be seen from the Table 4 that there is significant difference in the vertical distribution whereas the horizontal distribution shows very little difference.

A significant observation made was the occurrence of juvenile clams during July, December, January and February during the years 1990, 1991 and 1992.

Table 4. Distribution of population of *M. glabratum* at the intertidal zone.

Year/ month	Percentage of population in the core area up in the beach face			Percentage of population in transect (m) up in the beach face A – F					
	1	2	3	A	B	C	D	E	F
1990									
Jul	44	56	0	10	25	20	10	15	20
Aug	31	56	13	25	17	8	17	25	8
Sep	23	62	15	12	19	23	15	12	19
Oct	20	70	10	20	30	10	10	10	20
Nov	50	50	0	14	19	19	19	14	15
Dec	7	89	4	7	13	13	20	27	20
1991									
Jan	42	53	5	17	8	21	17	21	16
Feb	75	25	0	19	22	25	19	6	19
Mar	56	44	0	19	13	10	17	22	19
Apr	43	57	0	14	18	18	14	21	15
May	43	50	7	11	16	15	26	16	16
Jun	32	64	4	20	10	25	20	20	15
Jul	36	64	0	12	19	13	12	19	25
Aug	36	46	18	7	21	21	22	14	15
Sep	30	50	20	19	23	10	19	19	10
Oct	25	58	17	12	18	12	23	17	18
Nov	39	50	11	14	21	7	22	15	21
Dec	18	75	7	13	20	27	13	14	13
1992									
Jan	57	36	7	29	7	21	21	7	15
Feb	71	29	0	18	9	9	18	18	28
Mar	44	56	0	6	18	18	23	18	17
Apr	40	60	0	25	15	20	10	15	15
May	33	67	0	11	21	16	20	21	11
Jun	23	71	6	11	17	16	17	22	17

Core areas : 1:2 m; 2:6 m; 3:10 m

3.3.3. Population density :

Table 5 shows the fluctuation in the population of clam at the study area during the period from July 1990 to June, 1992. The density of population varied between 0-4 m, 5-8 m and 9-12 m. But there was little difference in numbers per transact between those at 10 m intervals and those at 5 m apart. The breadth of the belt in which clams found dispersed mostly was from the low water mark upto 12 m which was normally the high water mark. The number of clams per square meter area at the core levels of 2.5 - 3.5 m (1), 5.5 - 6.5 m (2) and 9.5 -10.5 m (3) also differed much from month to month in most of time. Area 1 (0-4 m) and 2 (5-8 m) had most of the populations. Here again, the distribution differed from month to month. The area 3 (9-12 m) had the very minimum population distributed. The average maximum and minimum densities per linear meter recorded was 25.4 in June 1991 and 4.2 in September 1991, whereas the average maximum and minimum densities per square metre were 41.7 (June, 1991) and 8.0 (November, 1990 and September, 1991).

The percentage of average population among the three zone core levels indicate that the zone 1 (0-4 m) had more or less 35 percent of the clam population, the zone 2 (5-8m) had more than 55 percent of the population and zone 3 (9-12 m) had only scarce population of about 5 percent (Table 5).

Table 5. Density of population of M. glabratum up in the beach face for the period from July 1990 - June 1992.

Year/ month		No/core sample			No/m^2 at core area			No/linear m			Average No/	
		1	2	3	1	2	3	0-4	5-8	9-12	m^2	Linear m
1990	Jul	4	5	0	19	17	1	48	42	3	12.30	7.75
	Aug	5	9	2	16	16	6	24	55	4	16.00	6.92
	Sep	3	8	2	6	58	6	14	160	3	23.3	14.75
	Oct	2	7	1	4	31	2	8	81	2	12.3	7.38
	Nov	2	2	0	9	14	1	25	48	3	8.0	6.33
	Dec	2	8	1	6	32	5	15	108	13	14.3	11.33
1991	Jan	8	10	1	24	35	1	60	89	2	20.0	12.58
	Feb	10	4	0	28	12	1	66	30	2	13.7	8.17
	Mar	5	4	0	17	14	0	31	37	1	10.3	5.75
	Apr	3	4	0	15	17	1	37	40	2	11.0	6.58
	May	6	7	1	20	22	4	42	59	10	15.3	9.25
	Jun	8	7	1	45	74	6	99	190	16	41.7	25.42
	Jul	8	6	0	24	31	0	52	98	2	18.3	12.67
	Aug	4	5	2	20	24	8	58	72	16	17.3	12.17
	Sep	2	3	5	8	13	3	12	30	8	8.0	4.17
	Oct	3	7	2	6	31	8	12	82	2	15.0	8.00
	Nov	7	9	2	18	32	8	40	76	18	19.3	11.17
	Dec	5	12	2	19	56	6	55	132	12	27	16.58
1992	Jan	8	5	1	28	24	5	62	63	10	19.0	11.25
	Feb	5	2	0	19	9	0	47	28	4	9.3	6.58
	Mar	4	5	0	14	22	0	35	60	3	12.0	8.17
	Apr	4	6	0	16	27	1	40	76	8	14.7	10.33
	May	1	2	0	14	16	1	43	57	4	10.3	8.67
	Jun	3	7	1	20	39	5	57	96	12	21.3	13.75
Total		112	144	24	415	666	79	982	1809	160	289.7	246.0
Average		4.7	6.0	1.0	17.3	27.8	3.3	40.9	75.4	6.7	16.24	10.25
%		40.0	51.4	1.0	35.8	57.4	3.7	33.3	61.3	5.4	-	-

A significant observation made during the study period revealed that the high densities of population in the 1-5 m area was due to the presence of more of young clams. This coincided with the post spawning periods. Otherwise the densities of adult and young clams are almost stable.

3.4. ALLOMETRIC RELATIONSHIPS IN MESODESMA GLABRATUM :

In order to determine the growth in relation to ecology and physiology of the clams, it is desirable to find out the various allometric relationships between total weight, length, width, thickness, shell weight and wet tissue weight. Among the populations of the clams in the offshore islands, the maximum size encountered was 50 mm (Rajan and Rajapandian, 1987). But from the present sampling, it was found that the adult individuals had reached a maximum length of 37.0 mm (Table 6).

The data on width and thickness were plotted against length as scattered diagram (Figs. 7 & 8). The scatter diagrams showed a clear straight-line relationship and hence a single regression line would describe the relationship in each case. The linear regression equation of the form $Y = a + bx$, where x is the independent variable, Y is the dependent variable and a and b are constants, was fitted by the method of least squares (Snedecor and Cochran, 1967) and the derived equations are given in Table 7. The values of correlation co-efficients (r) are very close to unity and showed high degree of correlation (Table 7). The

Table 6. Data on Length (1) and corresponding Width (2), Thickness (3), Weight (4), Shell weight (5), Flesh weight (6) and Dry flesh weight (7) of *M. glabratum*

S.No.	1	2	3	4	5	6	7
1	4.50	3.50	1.00	0.05	0.03	0.01	-
2	5.20	4.05	1.19	0.06	0.05	0.01	-
3	6.49	4.96	1.69	0.10	0.07	0.01	-
4	7.20	5.73	2.00	0.13	0.11	0.0125	-
5	8.20	6.55	2.64	0.18	0.13	0.0175	-
6	9.29	7.59	3.35	0.23	0.17	0.024	0.01
7	10.23	8.31	4.01	0.35	0.21	0.05	0.04
8	11.32	8.96	4.36	0.37	0.26	0.06	0.02
9	12.15	9.95	5.16	0.49	0.36	0.084	0.02
10	13.33	10.75	5.30	0.65	0.45	0.09	0.02
11	14.17	11.54	5.80	0.70	0.51	0.10	0.02
12	15.31	12.34	6.39	0.97	0.68	0.12	0.03
13	16.31	12.67	6.56	1.08	0.81	0.15	0.18
14	17.33	13.63	7.28	1.38	1.04	0.17	0.04
15	18.28	14.53	7.93	1.59	1.15	0.18	0.04
16	19.42	15.19	8.33	1.78	1.26	0.19	0.05
17	20.36	15.95	8.56	2.07	1.56	0.20	0.07

Table continued..

18	21.32	16.82	9.36	2.58	1.90	0.29	0.07
19	22.31	17.85	9.83	2.96	2.22	0.34	0.08
20	23.39	18.12	10.32	3.20	2.43	0.36	0.10
21	24.41	18.64	10.71	3.51	2.57	0.39	0.14
22	25.33	19.86	11.41	4.41	3.34	0.50	0.15
23	26.27	20.56	12.01	5.01	3.85	0.54	0.18
24	27.28	21.26	12.47	5.48	3.94	0.62	0.20
25	28.41	22.04	13.08	6.30	4.75	0.67	0.21
26	29.37	22.96	13.32	6.55	5.12	0.75	0.22
27	30.26	23.59	14.00	7.78	5.89	0.81	0.22
28	31.22	24.28	14.28	8.17	6.16	0.85	0.28
29	32.21	24.6	14.64	8.20	6.25	0.88	0.29
30	33.28	25.74	15.05	9.53	7.07	1.09	0.33
31	34.30	25.82	15.40	10.06	7.43	1.11	0.34
32	35.23	26.55	15.65	10.37	7.81	1.15	0.34
33	36.08	27.1	16.34	11.82	8.61	1.21	0.38
34	37.00	27.9	17.33	13.63	10.56	1.55	0.41

Fig. 7. Length - width relationship in the wedge clam *Mesodesma glabratum*.

$Y = 0.55269 + 0.75173\ X$

Fig.7

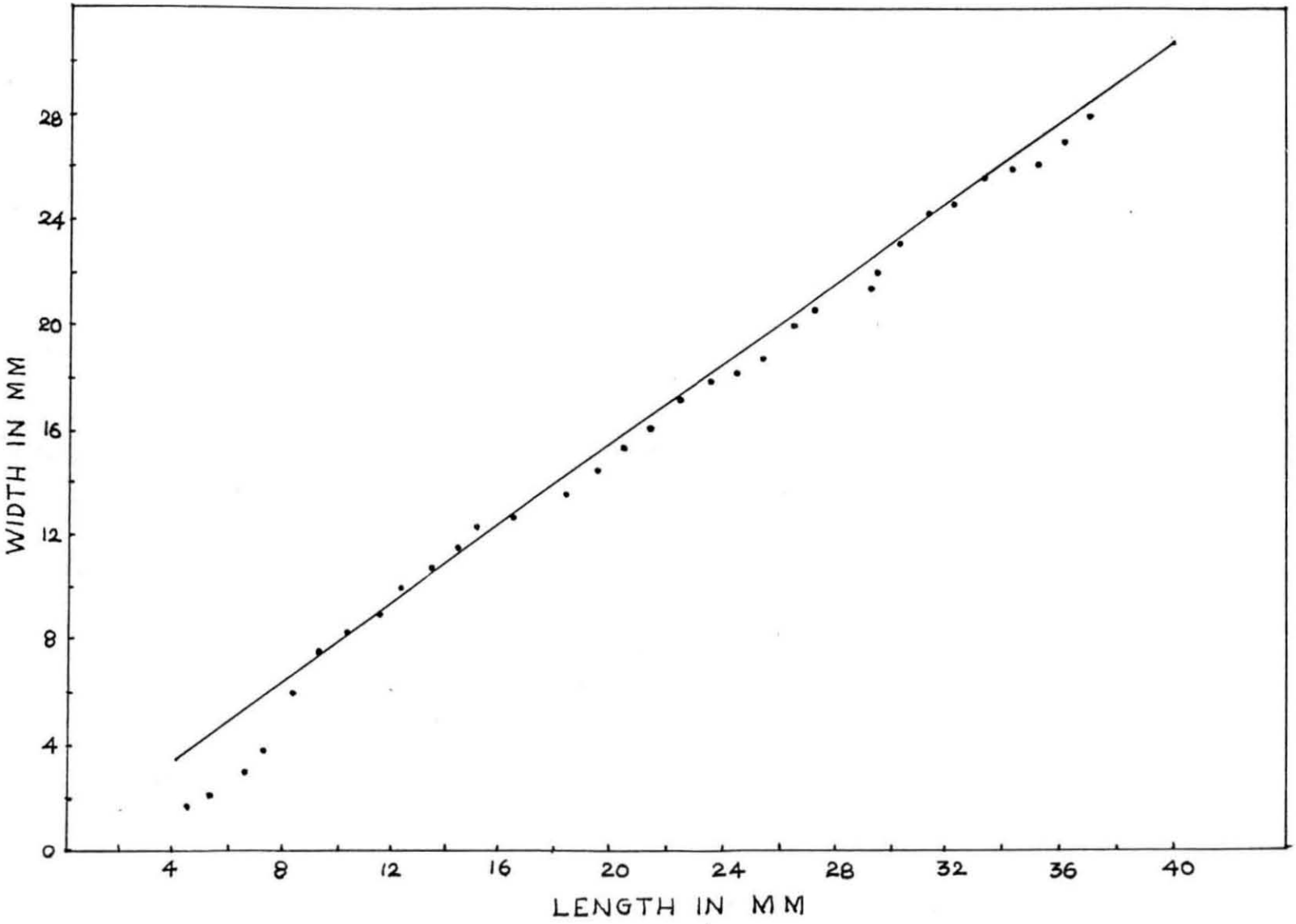
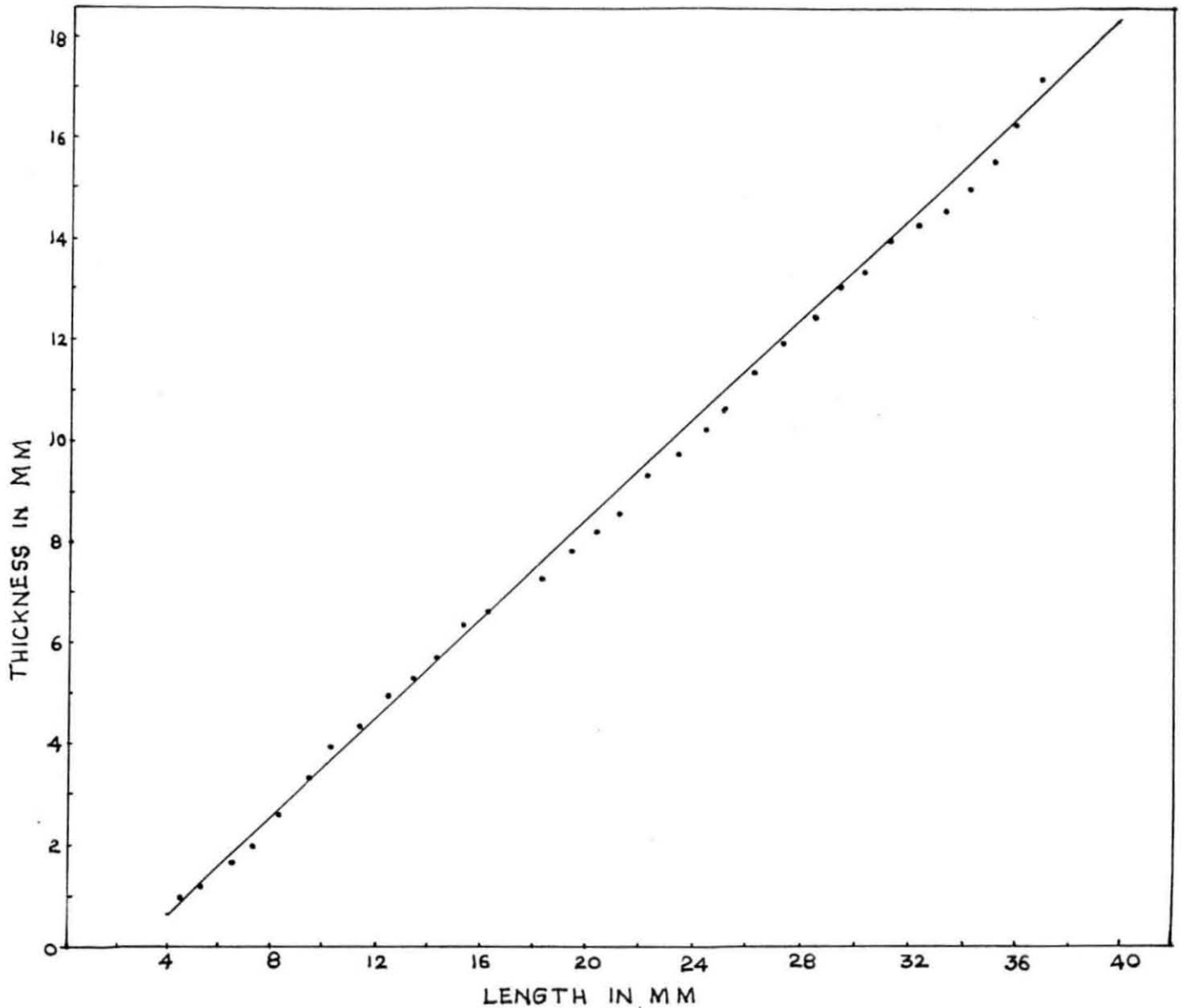

WIDTH IN MM
0
4
8
12
16
20
24
28
4
8
12
16
20
24
28
32
36
40
LENGTH IN MM

Fig. 8. Length - thickness relationship in the wedge clam Mesodesma glabratum.

$$Y = -1.24513 + 0.49111\ X$$

Fig.8


THICKNESS IN MM
0
2
4
6
8
10
12
14
16
18
4
8
12
16
20
24
28
32
36
40
LENGTH IN MM

linearity in the relationship between the different parameters analysed indicate that there is no change of form during its entire period of growth.

3.4.1. Length weight relationship :

A simple plotting of total weight against length on graph paper suggested a curvilinear relationship for the entire range of data. Hence, after the logarithmic transformation of the measurement, the straight line that is obtained would describe the relationship for the entire range (Fig.9). Hence the allometric graph equation $W = a L^{b}$, where W is the weight of the clam, L is the length, a and b are constants, was fitted to the data of M. glabratum.

The straight line equation obtained was as follows :

Log Wt = - 3.26255 + 2.76816 Log L.

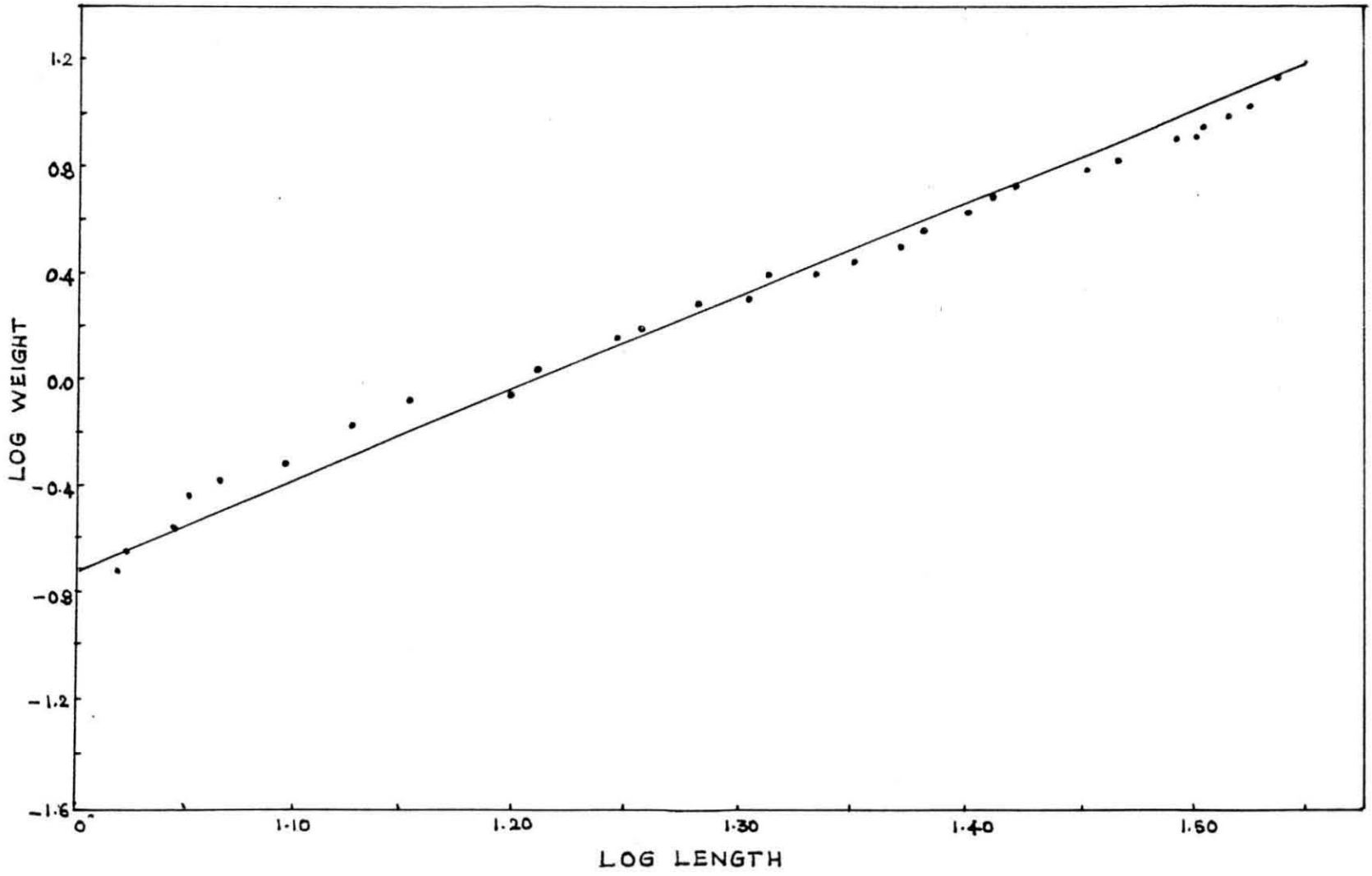
with its exponential form as

$$Wt = 0.0001456\ L^{2.76816}$$

From the length-weight relationship the 't' test showed that b is not significantly different from 3 confirming that the growth is isometric (Table 6). It may also be seen from the Figs. 7, 8 & 9, that weight, width and thickness vary proportionately to the length in all size groups, thereby indicating that the general form is more or less the same throughout its life from the size of 4.5 mm length. Hence change of form does not occur in M. glabratum in due course of time. The

Fig. 9. Length - weight relationship in the wedge clam *Mesodesma glabratum*.
Log W = -3.26255 + 2.76816 Log L

Fig.9


1·2
0·8
0·4
0·0
-0·4
-0·8
-1·2
-1·6
LOG WEIGHT
1·00
1·10
1·20
1·30
1·40
1·50
LOG LENGTH

values of the correlation coefficients (r) between length and various other body proportion studied (Table 7) are very close to unity showing high degree of correlation.

3.5. AGE AND GROWTH :

For the purpose of the study of age and growth, data on the length frequency distribution of the clams, collected for the period from July 1990 to June 1992 was used. In all, a total of 1850 clam ranging in size from 2.0mm to 37mm were measured. From the study on the reproductive cycle of M. glabratum, it is understood that spawning commences in January and extends upto June as shown by the occurrence of clams with spent gonads during this period. This was confirmed by the appearance of juvenile clams from April to June. As spawning in Mesodesma occurs for a continuous period of 6 months, there appears to be a lot of masking effect on the successive modes in the length frequency distribution. But it was found that spawning is at its peak during February to March and the settlement of spat takes place in the later part of March and April.

It could be seen from the length frequency distribution given in the Table 8 for the period 1990 - 91 and Table 9 for the year 1991-92 that the number of modes vary from 2 to 5. Except in March 1992 in all other months there are two or more modes available. During 1990-91 there appears to be 2 year-classes available in July 1990 in the size range at 9.0-10.9mm to

Table 7. Allometric relationship between various morphological characters in the population of *M. glabratum*

Relationship Y/X	Regression equation	Correlation coefficient (r)	ts	Whether b is significantly different from 3
Total Wt (Y) on Length (X)	Log W = -3.26255 + 2.76816 Log L	0.9978	17.478	yes
Width (Y) on Length (X)	Y = 0.55269 + 0.75173 X	0.9992	139.503	yes
Thickness (Y) on Length (X)	Y = -1.24513 + 0.49111 X	0.9992	101.360	yes
Thickness (Y) on Width	Y = -1.59992 + 0.65698 X	0.9993	212.663	yes
Wet tissue (Y) on Total Wt (X)	Y = 0.00558 + 0.10864 X	0.9970	40.973	yes
Shell Wt (Y) on Length (X)	Log W = -3.44206 + 2.80452 Log L	0.9986	76.014	yes
Shell Wt (Y) on Total Wt (X)	Y = -0.02393 + 0.75360 X	0.9996	57.421	yes
Dry Tissue Wt (Y) on Wet Tissue Wt (X)	Y = 0.00408 + 0.29312 X	0.9907	25.240	yes

Table 8. Size groups of animals represented during July 1990 to June 1991

Size Group (mm)	Mid length (mm)	1990 Jul	Aug	Sep	Oct	Nov	Dec	1991 Jan	Feb	Mar	Apr	May	Jun
1.0- 2.9	2.0	-	-	-	-	-	-	-	-	-	-	-	-
3.0- 4.9	4.0	-	-	-	-	-	-	-	-	-	-	1	-
5.0- 6.9	6.0	-	-	-	-	-	-	-	-	-	-	2	-
7.0- 8.9	8.0	-	-	-	-	-	-	-	-	-	-	1	1
9.0-10.9	10.0	1	-	-	-	-	-	-	-	-	-	-	4
11.0-12.9	12.0	2	-	-	-	-	-	-	-	-	-	-	2
13.0-14.9	14.0	4	3	-	-	-	2	-	-	-	-	-	-
15.0-16.9	16.0	3	2	2	-	-	7	3	-	-	-	-	-
17.0-18.9	18.0	1	2	1	1	2	8	5	1	-	-	-	-
19.0-20.9	20.0	-	1	1	1	3	7	6	2	-	-	-	-
21.0-22.9	22.0	-	-	-	-	6	11	12	-	1	1	-	-
23.0-24.9	24.0	12	3	-	-	15	9	20	11	8	3	2	1
25.0-26.9	26.0	15	17	3	1	-	4	15	10	7	5	2	3
27.0-28.9	28.0	19	26	11	4	-	2	5	8	14	15	12	7
29.0-30.9	30.0	11	21	27	12	7	-	7	23	16	13	9	13
31.0-32.9	32.0	5	13	15	11	17	-	2	12	18	32	13	11
33.7-34.9	34.0	4	7	10	16	15	12	-	17	10	17	17	12
35.0-36.9	36.0	2	3	5	3	4	11	13	5	4	12	9	12
37.0-38.9	38.0	1	2	-	1	1	2	2	1	2	2	2	4
Total		80	100	75	50	70	75	90	90	80	100	70	70

Table 9. Size groups of animals represented during July 1991 to June 1992

Size group (mm)	Mid length (mm)	1991 Jul	Aug	Sep	Oct	Nov	Dec	1992 Jan	Feb	Mar	Apr	May	Jun
1.0 - 2.9	2.0	-	-	-	-	-	-	-	-	-	22	2	-
3.0 - 4.9	4.0	-	-	-	-	-	-	-	-	-	2	17	2
5.0 - 6.9	6.0	-	-	-	-	-	-	-	-	-	1	9	14
7.0 - 8.9	8.0	-	-	-	-	-	-	-	-	-	-	5	15
9.0 -10.9	10.0	1	-	-	-	-	-	-	-	-	-	8	12
11.0-12.9	12.0	3	3	1	-	-	-	-	-	-	-	5	9
13.0-14.9	14.0	3	4	3	2	1	1	-	-	-	-	-	5
15.0-16.9	16.0	-	2	4	3	1	1	1	-	-	-	-	2
17.0-18.9	18.0	-	1	2	4	2	3	3	1	-	-	-	-
19.0-20.9	20.0	-	-	1	4	5	3	6	3	1	-	-	-
21.0-22.9	22.0	-	-	1	2	6	4	8	6	2	1	-	-
23.0-24.9	24.0	-	-	-	1	1	8	12	7	4	2	2	2
25.0-26.9	26.0	2	2	1	-	1	2	5	20	7	12	4	2
27.0-28.9	28.0	5	3	2	-	-	1	4	6	17	22	15	5
29.0-30.9	30.0	15	8	10	8	4	2	1	19	16	22	16	6
31.0-32.9	32.0	17	12	19	22	12	17	18	13	13	12	16	12
33.0-34.9	34.0	9	12	13	10	23	13	13	3	10	13	12	9
35.0-36.9	36.0	4	2	2	3	4	3	4	2	-	2	2	4
37.0-38.9	38.0	1	1	1	1	-	2	-	-	-	2	2	1
Total		60	50	60	60	60	60	75	80	70	110	115	100

17.0-18.9 mm with mode at 13.0-14.9 mm and another in the size range from 23.0-24.9 mm to 37.0-38.9 mm with mode at 27.0-28.9 mm. These two year classes have got merged into one in due course of time in the month of April 1991. The juvenile clams were absent during this period and it appeared only in May 1991 in the size range at 3.0-4.9 mm with mode at 5.0-6.9 mm. The progression of this mode in subsequent month is clearly seen during July 1991 to March 1992. The recruitment of the juveniles was observed at 1.0-2.9 mm size during April 1992. The progression of the modes for subsequent months during 1990-91 and 1991-92 are shown in Figs.10 and 11 respectively.

Assuming that the growth rate is expected to be faster during the early period of life, the clams with a length of 10 mm in July 1990, may be considered as 3 months old. Therefore assuming the spat settlement would have taken place in April 1990, it is reasonable to infer that the clams attain a length of 29 mm at the end of one year registering a growth rate of 2.42 mm per month and 36 mm at the end of 2 years registering a growth rate of 0.58 mm during the second year. From the third year onwards the mode at 37 mm does not make any progression remaining stationary in the subsequent months (Table 6).

The juvenile clams of the 1990 recruitment (1990 year class) ranged in size between 10 and 18mm with mode at 14.0 mm. The mode progressed to 24 mm in December 1990, 32 mm in March

Fig. 10. Percentage length frequency distribution of Mesodesma glabratum. for the successive months of the period July 1990 through June 1991.

Fig.10

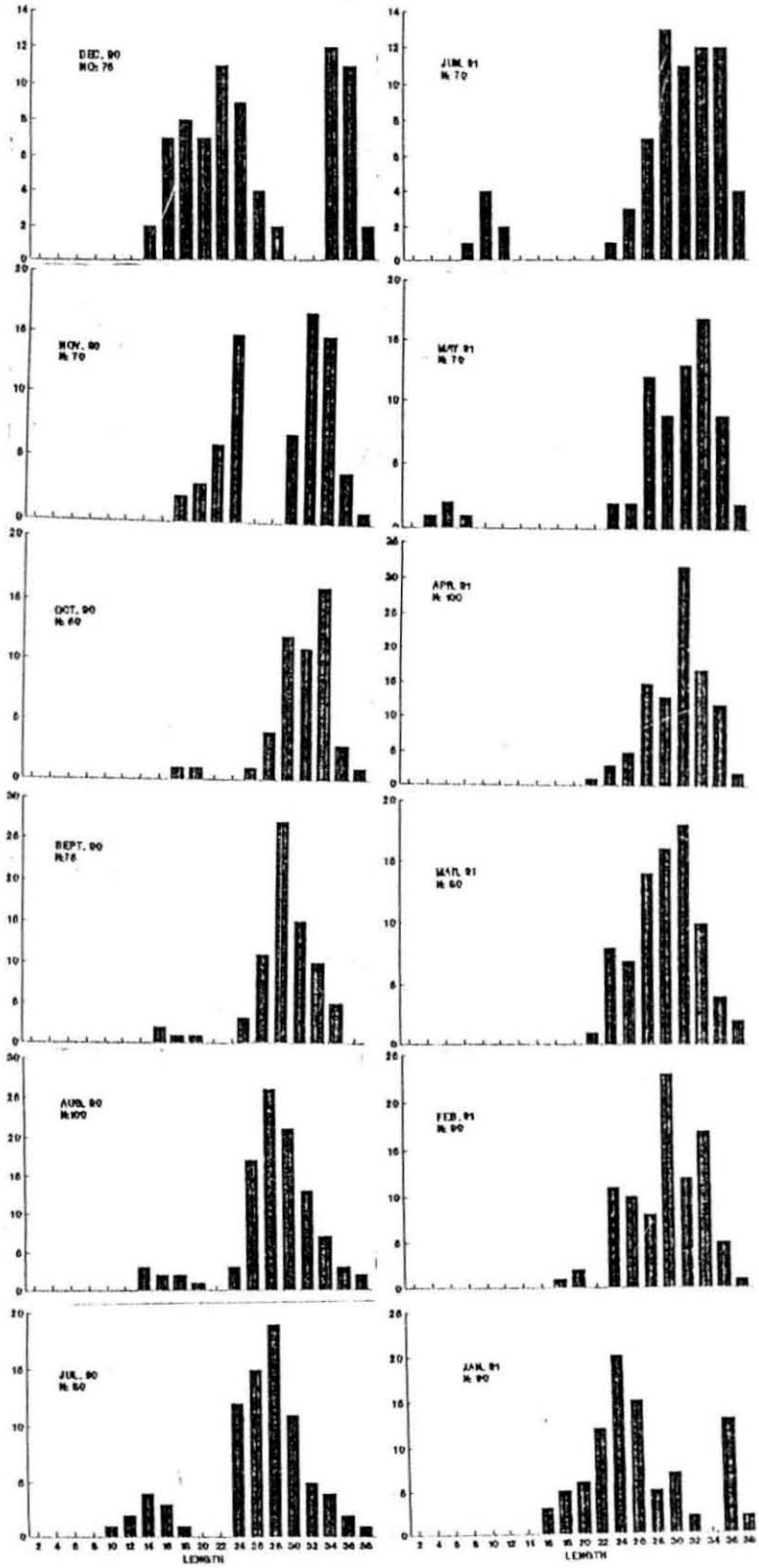
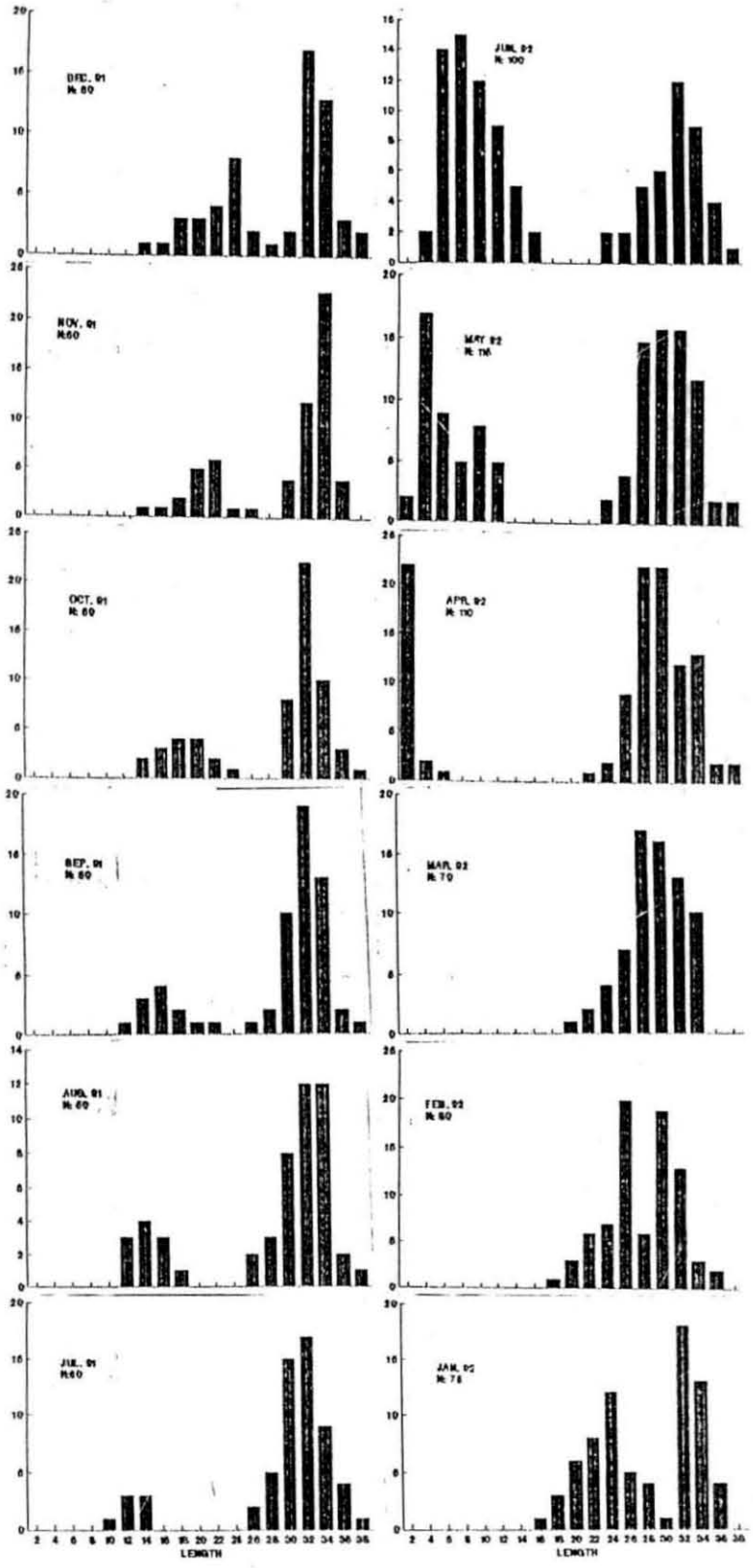

DEC. 90
JUNE 91
NOV. 90
MAY 91
OCT. 90
APR. 91
SEPT. 90
MAR. 91
AUG. 90
FEB. 91
JUL. 90
JAN. 91
LENGTH
LENGTH

Fig. 11. Percentage length frequency distribution of Mesodesma glabratum. for the successive months of the period July 1991 through June 1992.

Fig.11


DEC. 91
N: 80
JUN. 92
N: 100
NOV. 91
N:80
MAY 92
OCT. 91
N: 80
APR. 92
SEP. 91
N: 80
MAR. 92
N: 70
AUG. 91
N: 80
FEB. 92
N: 80
JUL. 91
N:80
JAN. 92
N: 78
LENGTH
LENGTH

1991 and 36 mm in June 1991. Assuming that the spat settlement would have taken place in the middle of March 1990, it is reasonable to infer that the clams attain a length of 29 mm in March 1991 registering a growth rate of 2.4 mm per month. The juvenile clam of the 1991 recruitment having a modal value of 6 mm in May 1991 recorded a steady growth and attained a growth of 24 mm in December 1991.

Among the adult clam belonging to the 1989 year class, the mode was at 28 mm in July 1990. It progressed to 34 mm in December 1990 and 36 mm in January 1991 and thereafter, it merged with older year class and lost its identity. Among the adult clams belonging to 1990 year class, the mode was 32 mm in July 1991. It progressed to 34 mm in August 1991 and merged with the 1989 year class clams and lost its identity. The maximum size of the clams encountered during the course of study was 37.0 mm.

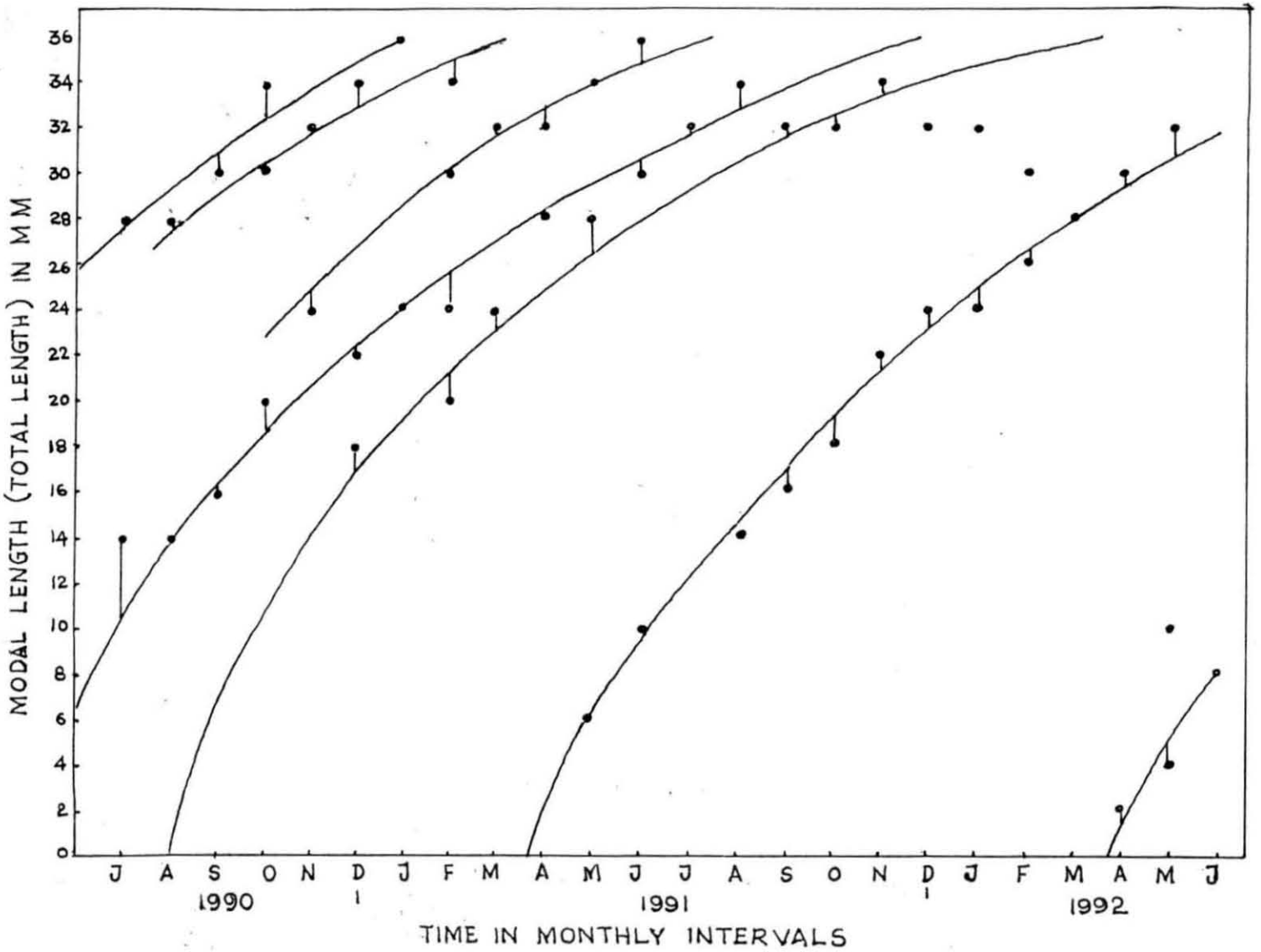
From the length frequency observation (Fig 12), it is possible to suggest that the clams attain a length of 29 mm at the end of one year and 36 mm at the end of 2 years and thereafter, progression of modes were not traceable. The length increments observed between one year old and two years old is about 7mm. The life span of the species may not exceed three years.

3.5.1. Fitting of von Bertalanffy's growth equation :

From the scatter diagram (Fig 12) the modal values in the same months of different years were pooled and the average

Fig. 12. Scatter diagram of modal length - month for *Mesodesma glabratum*.

Fig.12


MODAL LENGTH (TOTAL LENGTH) IN MM
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
J A S O N D J F M A M J J A S O N D J F M A M J
1990
1991
1992
TIME IN MONTHLY INTERVALS

lengths (Lt) obtained at each month were plotted against those of the succeeding months (Lt + 1) which resulted in a straight line distribution (Walford, 1946).

Based on the concept that growth is the net result of anabolism and catabolism, von Bertalanffy (1938) formulated a growth equation which according to Beverton (1954) and Beverton and Holt (1957) produced a growth cure that fits well with the growth of many species. This equation gives linear relationship between length at time t and at time t + 1 and is expressed as

$$Lt = L\infty\ (1-e^{-k(t-to)}) \quad ---1$$

when Lt = length at age t; $L\infty$ = maximum or asymptotic length a clam can theoretically reach; e = Napier's base or natural logarithm; k = coefficient of catabolism; t = age of clam; t o = arbitrary origin of the growth curve or the theoretical time when the clam is in zero length.

3.5.2. The estimation of growth parameter by arithmetric method :

von Bertalanffy's growth equation (1) can be rewritten in the following form :

$$lt + 1 = L\infty\ (1-e^{-k}) + e^{-k}\ lt \quad ----2$$

This is a linear equation in terms of Lt and Lt^{+1}, which Bagenal (1955 a, 1955 b) used to study the growth of rough data.

This is the same as

$$L_{t}^{+1} = a + b\, l_t \qquad \text{----3}$$

in which $a = L_{\infty}(1-e^{-k})$ ----4

and $b = e^{-k}$ ----5

The constants L_{∞} and e^{-k} can be solved by applying the least square methods and shown below, using values of L_t and L_t^{+1} in the age length data of M. glabratum obtained from scatter diagram analysis of length frequency.

	L_t	L_t^{+1}
1	3.2	6.3
2	6.3	9.2
3	9.2	12.4
4	12.4	14.8
5	14.8	17.2
6	17.2	19.5
7	19.5	21.6
8	21.6	23.5
9	23.5	26.8
10	26.8	28.2
11	28.2	29.4
12	29.4	30.6
13	30.6	31.9

14	31.9	32.9
15	32.9	33.8
16	33.8	34.7
17	34.7	35.4

The estimated values of b and a are :

$b = 0.9230$ and $a = 3.5109$

$b = e^{-k} = 0.9230$

Substituting the values of 'b' and 'a' in equation (4) we have,

$3.5109 = L\infty (1-0.9230)$

and therefore

$$L\infty = \frac{3.5109}{1-0.9230} = 45.6 \text{ mm}$$

The values 'k' can be determined from the value of e^{-k} using the formula

$$b = e^{-k}$$

$$k = \log e$$

$$b = \log e^{0.9230} = -8.01604448 \quad E \quad -0.2/\text{month}$$

(or)0.9615/year

$$to = \frac{1}{k}\left\{\log e\frac{L\infty - Lt}{L\infty} + kt\right\} \text{-------6}$$

Based on the formula (6) the average value of t o calculated for different months is found to be

= 0.0023 years for M. glabratum

Thus the length equation (1), when the values for L oo, k and to are substituted become :

$$lt = 45.6\ (1 - e^{-0.9615\ (t\ -\ 0.0023)})$$

3.5.3. Estimation of growth parameter by graphic method :

The parameters of growth equation (1) may also be obtained graphically by the Ford-Walford plot (Ford, 1933 and Walford, 1946) by plotting L_{t+1} against L_t (Fig.13) on the basis of lengths attained at intervals of one month. The regression line was fitted by the method of least squares. The point of interception of the growth line by the bisector gave the value of L_∞ as 45.6 mm. The slope of the growth line is equal to e^{-k} of equation 1 from which k was found out to be 0.9615 when the values of Log e $(L_\infty - L_t)$ are plotted against the corresponding ages in terms of months, a straight line is obtained (Fig.13) whose Y intercept is equal to Log e L_∞ + K to which was found to be 3.8221.

According to Ricker (1958)

$$t_o = \frac{(\text{Log } e\ L_\infty + Kt_o) - \log e\ L_\infty}{k}$$

By substituting the values

$$t_o = \frac{3.8221 - 3.8199}{0.9715} = 0.0023$$

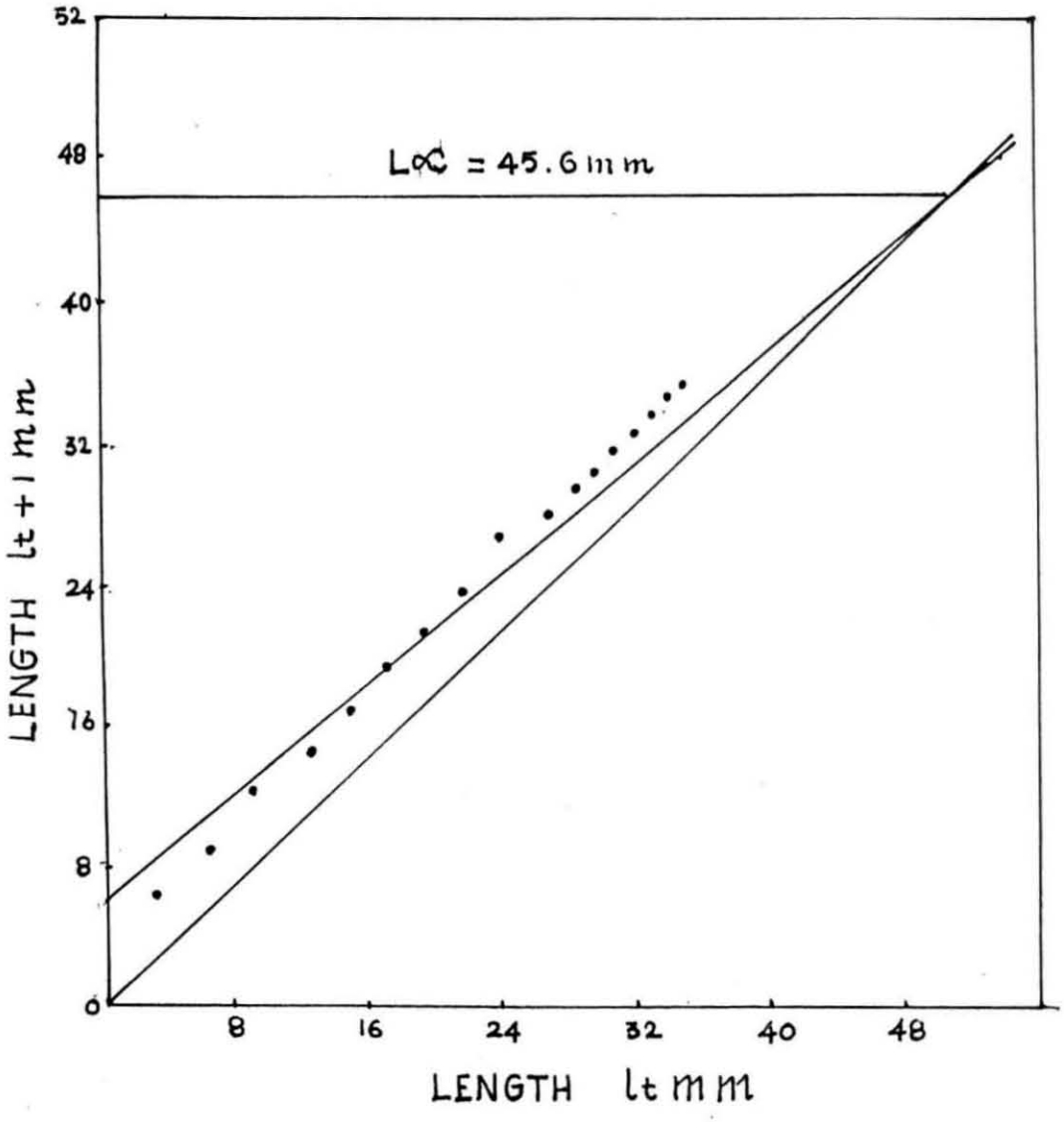
Thus the equation (1) can be written as :

$$L_t = 45.6\ [1 - e^{-0.9615\ (t-0.0023)}] \quad \text{-----8}$$

which is almost same as equation (7).

Fig. 13. Ford-Walford plot of the growth of *Mesodesma glabratum*.

Fig.13


52
48
40
32
24
16
8
0
L∞ = 45.6 mm
LENGTH lt + 1 mm
8
16
24
32
40
48
LENGTH lt mm

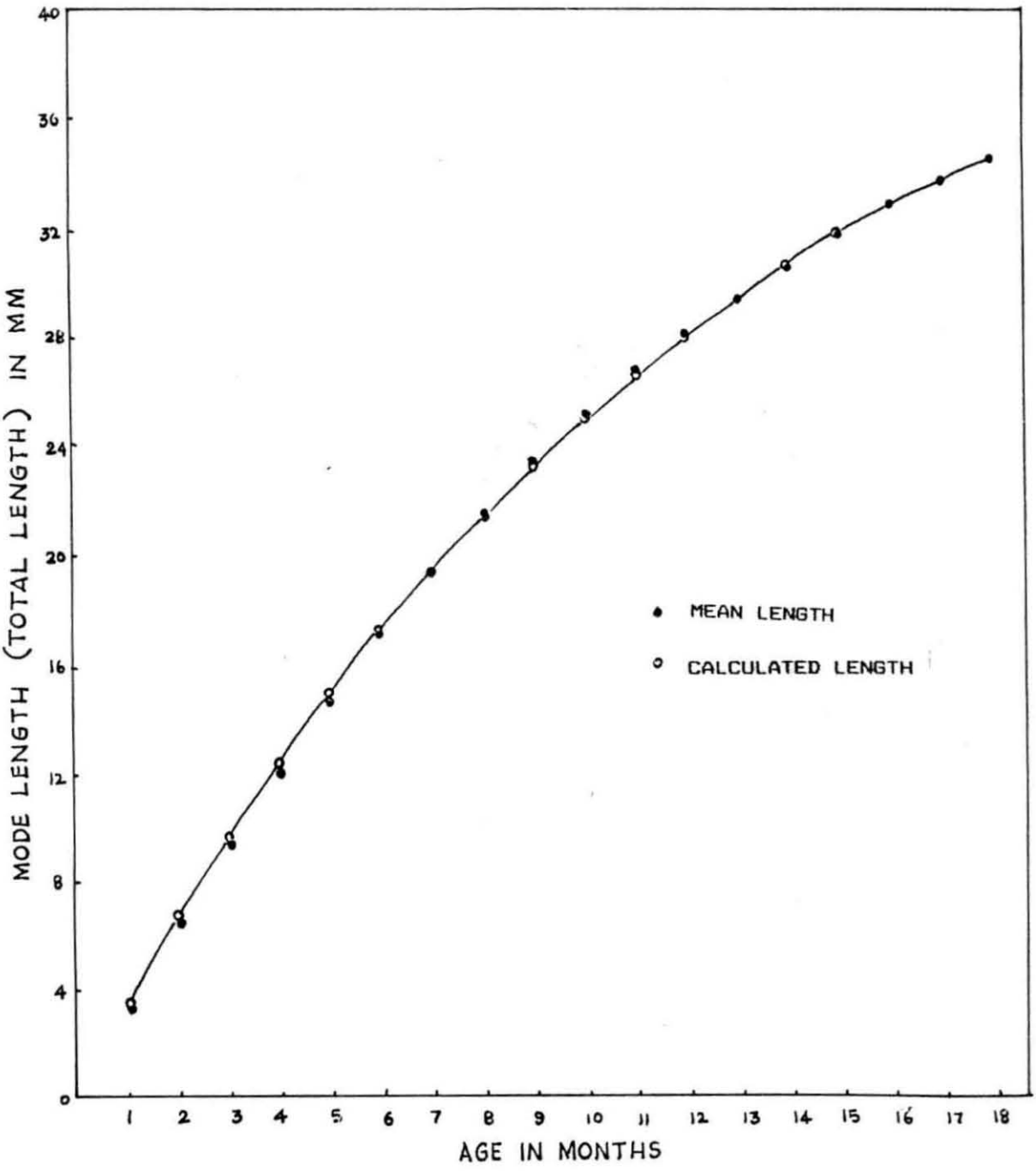
Using the equation (7) the theoretical values of 't' L' for the clam upto 2 years of age were calculated.

Age in month	Theoretical length	Age in month	Theoretical length
1	3.4	13	29.4
2	6.7	14	30.7
3	9.6	15	31.8
4	12.4	16	32.9
5	15.0	17	33.8
6	17.3	18	34.7
7	19.5	19	35.8
8	21.5	20	36.6
9	23.3	21	37.4
10	25.0	22	38.1
11	26.6	23	38.7
12	28.1	24	39.3

The calculated lengths by the above growth equation at ages 1 and 2 are 28.1 mm and 39.3 mm respectively (Fig.14). The length frequency studies showed that on the completion of 1 and 2 years, the clams were found to attained a length of 28.1 and 39.3 mm (Fig.14). The length-at-age data arrived by these two methods are similar. From the rate of growth estimated and the asymptotic length obtained, it can be seen that about 60% of the growth of the clam and even in these 50% coming in the first nine months. The L oo obtained is 45.6 mm which is close to the maximum length of clam obtained among the populations of the offshore islands.

Fig. 14. Mean lengths at age in months based on the scatter diagram and mean lengths at age in months based on the calculated lengths for Mesodesma glabratum.

Fig.14


MODE LENGTH (TOTAL LENGTH) IN MM
AGE IN MONTHS
MEAN LENGTH
CALCULATED LENGTH
0
4
8
12
16
20
24
28
32
36
40
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

3.6. GAMETOGENESIS :

In the clams in general, the maturation of male and female gonads does not make any external difference in size and colour. M. glabratum is not an exception in this matter. Only the smear and histological examination of the gonads can indicate the sex of the clam. In view of the difficulties faced in determining the males and females and their stages of maturity, histological examination becomes necessary. Only smear examination of the gonad will give a complete picture of the gonad. The hermaphroditic condition of the clam cannot be correctly identified by examining the smear alone. Therefore in the present work all the criteria like observation on the external appearance of the gonad, smear examination and histological studies of both male and female gonads have been taken up in detail.

The immature (undifferentiated) gonad is small and inconspicuous. It is transparent and colourless. The follicles may not be visible. The gonad wall is thin and if pierced, water alone oozes out. The connective tissues begin to appear between follicles. Spermatogonia in the case of males and oogonia in the case of females begin to appear in close contact with the germinal epithelium adjacent to the intestinal loop.

3.6.1. Oogensis :

The different phases of oogenesis have been described by Raven (1964) in Lymnea stagnalis , Galtsoff (1964) in American

rock oyster Tranter (1958 a,b) in Australian pearl oyster and Chellam (1987) in Indian pearl oyster Pinctada fucata sp . In all these bivalves, the primordial cells give rise to primary oogonia in females. After repeated mitotic divisions of the oogonia, the secondary oogonia arise which in turn give rise to the oocytes. These are the result of the vegetative phase of oogenesis. The oocyte passes throughout the so called premieotic division in which the prophasic changes of the chromatids inside the germinal vesicle are accomplished. However, further division is stopped here at this stage in order to facilitate the accumulation of yolk materials characteristic of the vitellogenic phase of oogenesis.

In many of the bivalve molluscs, further meiotic divisions are taking place only after ovulation as characterised by the extrusion of polar body (Raven, 1958; Wada, 1968; Galtsoff 1964; Tranter, 1958 a, b and Alagarswami et al., 1983).

In M. glabratum, from the cytological examination of the ovary during different months of observation, five stages of gonad could be identified and distinguished. The criteria by which the stages were defined is given in Table 10. In stage I (Developing/Maturing stage), the gonad is small, inconspicuous and colourless. As the stage advances, the gonad becomes larger in size, thick and firm. The colour of the gonad, in most cases, is transparent and colourless. In stage II (Matured/Ripe), the

Table 10. External appearance, cytological and histological details of gonad stage in M. glabratum

Gonad stage	Description	
	Smear observation	Histological observation
I A Early maturing	Gonad becomes larger and flabby depending upon the size of the clam; follicles larger and denser. Alimentary canal is visible; little connective tissue.	Male : Follicles contain mainly of centripedal band of spermatogonia on follicle walls; spermatocyte and spermatids; no spermatozoa. Female : Oogonia arising from stem cells in the follicle wall; few attached primary oocytes; no free oocytes.
I B Late maturing	Gonad thicker, firm and larger; follicles larger and becoming denser. Little connective tissue.	Male : Follicles contain predominently spermatids and spermotozoa. Spermatozoa with tail towards lumen. Follicles half filled in the gonad area; Free spermotozoa sometimes present in the lumen. Female: Secondary oocytes attached to the follicle wall by slender stalks. A few free oocytes in the lumen. Follicles increase in size.
II Matured (Ripe)	Maximum gonad size; full and plumpy and becomes creamy in colour. Male : Follicle packed to the periphery. In fresh smear, spermotozoa display various degrees of motility. Female: Follicles crowded with free oocytes.	Male : Lumen of large follicles with bunches of spermatozoa with tail oriented towards the large follicle lumen. In fully ripe gonad, spermatozoa fill up the lumen; little connective tissue. Female: Follicles filled predominantly with large free oocytes with distinct nucleus and nucleolus, round to oval; follicles closely packed, no interfollicular connective tissue; follicle wall sometimes found breaking.

Table -- continued

III Partially spawned	Gonad becomes dull, flabby and loose depending on the number of follicles emptied. The colour becomes greyish. The zones of unspawned follicles exhibit ripe germ shells. In spawning males, patches of translucent tissue indicating empty and full follicles. Patches of translucent tissue indicating empty and full follicles. In fresh smears, sperms are very active.	Male : Few follicles empty or emptying. Mass of spermotozoa separated from follicular walls farming a 'plug' in lumen. Few individual spermotozoa in the lumen. Female: Many follicles empty. Few phagocytes may present
IV Spent	Gonad shrinks and becomes loose and translucent. Follicle wall ruptured. Most follicle empty with a few residual sperm or egg.	Male : Follicle empty and collapsed with a few residual leftout spermatozoa. Phagocytes some times present. Female: Follicles empty and shape collapsed. Few residual oocytes occasionally present; relict oocytes present. Few phagocytes present.
V Resting/ Indeterminables	Gonad shrinks further with collapsed follicles. Much connective tissue. Residual eggs and spermotozoa mostly encircled by phagocytes. Undifferentiated germ cells lining the walls began to appear in some cases.	

gonad is full and plumpy and attains the maximum size. The colour of the gonad becomes creamy with very little connective tissue. In stage III (Partially spawned), the gonad becomes dull, flabby and loose in consistency. Colour of the gonad slightly changes to grey. Follicle wall ruptures and empty with a few residual sperms/eggs. A few phagocytes may be present. In stage V (Indeterminable/Resting), the gonad shrinks further and becomes translucent. The wall of the gonad with much connective tissues. The residual eggs and spermatozoa if present are encircled by phagocytes. Sex cannot be differentiated by smear examination.

Stage I (Maturing/Developing) :

The primary germ cells begin to develop in the early maturing stage, They undergo mitotic division and give rise to oogonia in this stage. The onset of oogenesis is indicated by the appearance, growth and spreading of follicles and the occurrence of oogonia and oocytes in the premeiotic stage. The oogonia are small and spherical in shape and the size ranges from 5 to 15 µm in diameter. (Table 11: Plate 2: Figs.15 & 16). The cytoplasm is small. The nucleus, nucleoplasm and nucleolus are not distinctly visible. Further growth of the oocytes and the formation of secondary oocytes indicates the gonadal maturity. In the late maturing stage a rapid increase in the size of follicles is seen. The follicles occupy more area among the connective tissue. In this stage, the size of oocytes varies between 24 um and 35 um.

Table 11. Sequence of oocyte development and nucleus (germinal vesicle) in different ovarian stages of M. glabratum

Size range oocyte µm	Stage I A	Stage I B	Stage II	Stage III	Size range nucleus µm	Stage I B	Stage II	Stage III
0.0-4.9	40	-	-	-	0.0-2.9	-	-	-
5.0-9.9	40	-	-	-	3.0-5.9	-	-	-
10.0-14.9	18	-	-	-	6.0-8.9	-	-	-
15.0-19.9	2	-	-	-	9.0-11.9	-	-	-
20.0-24.9	-	8	-	-	12.0-14.9	16	-	-
25.0-29.9	-	28	-	-	15.0-17.9	44	-	-
30.0-34.9	-	48	-	-	18.0-20.9	36	2	1
35.0-39.9	-	16	18	24	21.0-23.9	4	16	23
40.0-44.9	-	-	31	33	24.0-26.9	-	48	57
45.0-49.9	-	-	33	31	27.0-29.9	-	15	17
50.0-54.9	-	-	13	11	30.0-32.9	-	15	2
55.0-59.9	-	-	4	1	33.0-35.9	-	3	-
60.0-64.9	-	-	1	-	36.0-38.9	-	1	-
Total	100	100	100	100		100	100	100
Minimum	4.00	24.00	36.60	36.60		12.80	18.30	20.00
Maximum	15.00	36.00	61.60	59.90		21.60	38.90	30.00
Mean	7.36	31.47	46.10	44.20		17.40	26.90	26.40
S.D	3.20	3.29	5.50	5.10		2.40	3.10	2.10
SE	0.12	0.06	0.08	0.08		0.06	0.06	0.04

Fig. 15. Sequence of growth of oocyte from stage I a to stage III in Mesodesma glabratum.

OOCYTE DIAMETER
AT VARIOUS STAGES

Fig.15

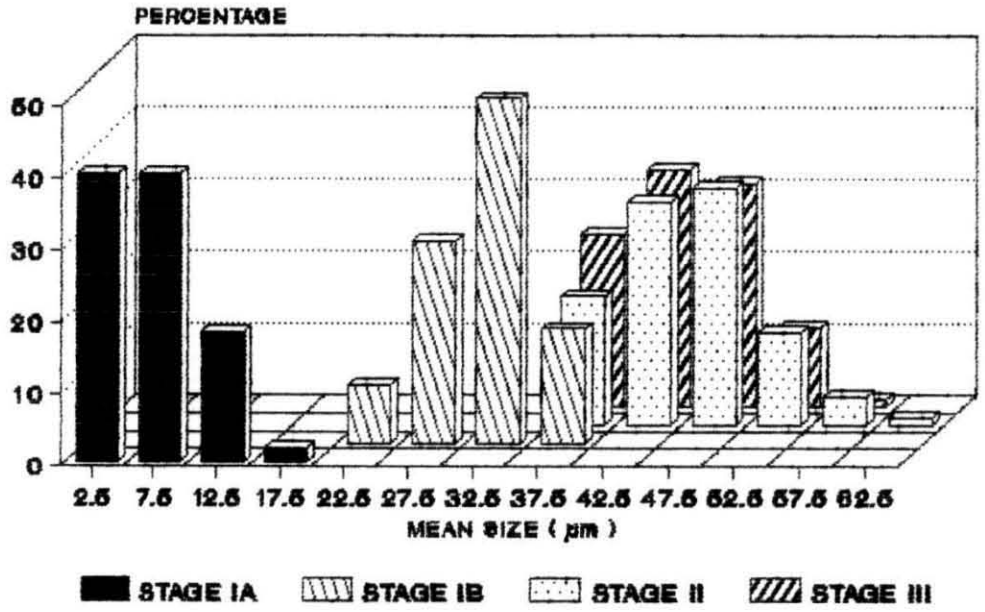
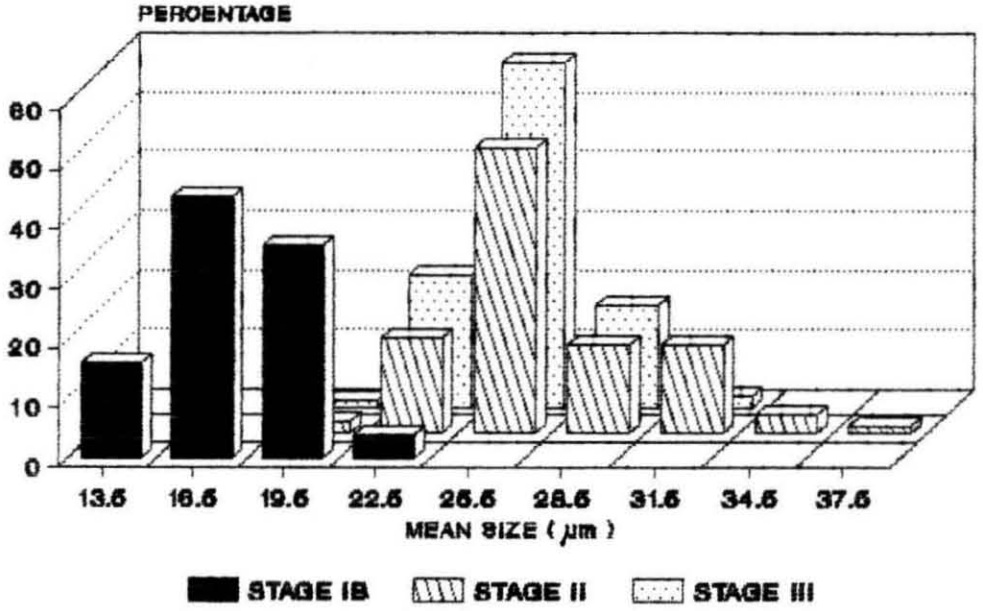


Fig. 16. Sequence of growth of germinal vesicle from stage I a to stage III in Mesodesma glabratum.

NUCLEUS DIAMETER
AT VARIOUS STAGES

Fig. 16



The cytoplasm becomes granular. The nucleus nucleoplasm and nucleolus are seen distinctly with dense chromatin adhering to the inner periphery of the nucleus.

Stage II (Mature/Ripe) :

The oocytes grow further, enlarged in size and become irregular in shape varying from suboval to columnar. Most of the large oocytes are attached to the follicular walls by slender stalks. Oocytes in the size range 40-50 μm are found in more numbers in this stage. The length of the stalk varies from oocyte to oocyte found in different areas of the gonad, the maximum length being 60 um. The stalk is broad at the base and stumpy or pointed at the tip. The size of the nucleus range between 18 to 33 μm. Dense granules occupy the periphery of the cytoplasm. The nuclear membrane is densely stained with haematoxylin. As the growth of the oocyte advances, the size of the stalk is reduced and it becomes more or less round. The diameter of the oocyte ranges between 35 - 60 μm at the time of release into the lumen. A fully ripe ovary is characterised by the occurrence of more detached oocytes in the lumen of the follicle. The nucleoplasm is clear with a large nucleolus. Faint strands of chromatin may be present in the cytoplasm in some cases. The diameter of the nucleolus ranges between 18-38 μm. The mean size of oocyte and nucleus is 46 and 27 μm respectively (Table 11: Plate 2: Figs. 15 & 16).

Plate 2.

A. Stage Ia. Cross section of early active male gonad showing spermatogonia and secondary spermatocytes (Bar = 100 μm)

B. Stage Ib. Male gonad with clusters of spermatids outside the core of spermatozoa (Bar = 100 μm)

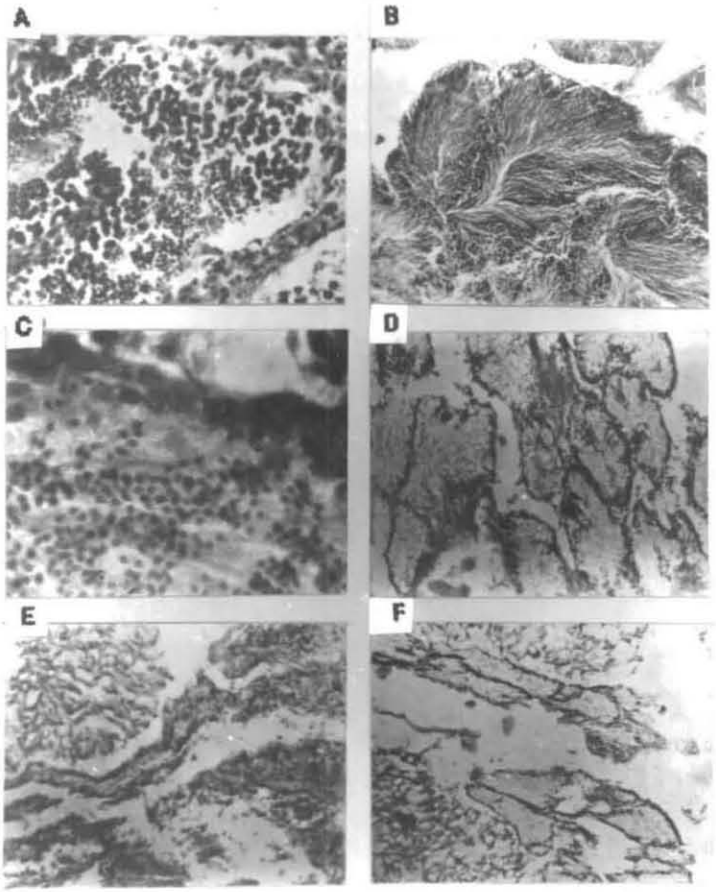
C. Stage II. Ripe testis. Streams of spermatozoa are arranged radially with their tails towards these centre of follicular lumen (Bar = 100 μm)

D. Stage III. Post-spawned testis with shrunken follicles (Bar = 100 μm)

E. Stage IV. Spent testis with shrunken and empty follicle space. Follicle walls ruptured.

F. Stage V. Cross section of resting indeterminable phase (Bar = 100 μm)

Plate 2



Stage III : (Partially spawned/Partially spent)

The follicle shrink and the follicle wall is ruptured. The follicle shows varying degrees of emptyness. The vesicular tissue, the connective tissue cells and free oocytes are found scattered in the lumen. The mean size of oocyte and nucleus is 44 μm and 26 μm respectively.The residual oocytes in the lumen are few. Phagocytes may appear in the interfollicular space in some cases (Table 11: Plate 2: Figs. 15 & 16).

Stage IV :(Spent)

The follicular walls are collapsed and shrink further, enclosing very few unspawned residual oocytes. The vesicular and connective tissue fill the interfollicular space. The ovary is in the regressive state. As a result of disintegration and cytolysis of the unspawned oocytes, phagocytes appear both inside and outside the follicles.

Stage V : (Indeterminable/Resting)

The gonad shrinks further with much connective tissue. The unspawned residual eggs are encircled by the phagocytes and digested. The cytolysis and digestion of the oocytes has been described by many workers on molluscan spawning (Cole, 1942; Rao, 1950; Durve, 1964; Miller, 1964; Tranter, 1958,a b; Chellam, 1987). In this stage the gonad enter into the indeterminable stage in which the sex of the clam becomes difficult to

determine. The gonad becomes translucent. Undifferentiated germ cells may appear along the walls. (Plate 2).

3.6.2. Spermatogenesis :

Stage I :(Developing/Maturing)

In the early maturing stage, the gonad is highly active. On the onset of the active phase, the follicles increase in size and their periphery contain numerous spermatogonia and a few spermatids radiating towards the lumen of the follicle. As the number of the spermatocytes increases, the spermatogonia lining the follicular well dwindle in number. The spermatogonia are easily recognised by their large nuclei with the cytoplasm enveloping them. The nuclei show faint radiating chromatin strands and a conspicuous nucleolus. The spermatogonia line up the follicular lumen along the follicular wall.

The secondary spermatocytes are present in large numbers along with the primary spermatocytes. The primary and secondary spermatocytes can be differentiated only by the size and staining intensity. The spermatids may be found outside close to the core of spermatozoa in layers. In this stage, the follicles contain predominantly with spermatids. The spermatozoa is characterised by their swirling pattern, the tail facing towards the centre of the lumen of the follicle.

Stage II :(Mature/Ripe)

As the gonad attains the ripe condition, the spermatids differentiate into spermatozoa and lie as a core in the lumen of the follicle. As the number of the spermatozoa increases, there is a corresponding decrease in the immature germ cells. A ripe gonad is characterised by bunches of spermatozoa arranged more or less radially with their tails facing towards the centre of the follicular lumen. In a fully ripe clam, gonad the entire lumen is filled with bunches of these spermatozoa.

Stage III : (Partially spawned/Partially spent)

The gonads of the partially spent clams are with shrunken follicles and ruptured follicular walls. In this stage, cores of disorganised cells including spermatids and secondary spermatocytes are found in the lumen. The vesicular connective tissue increases. In some cases, the presence of phagocytic cells inside the lumen is noticed (Plate 3).

Stage IV : (Spent)

The follicles shrink further and collapse. The vesicular connective tissue increases. Phagocytes present in the lumen engulf the leftout residual pockets of spermatids (Plate 3).

Plate 3. Histological and cytological details of gonadal phases in Mesodesma glabratum

A. Stage I. Cross section of ovary showing the proliferation of oogonia and oocytes. (Bar = 100 μm)

B. Stage II. Cross section of ripe ovary showing fully packed follicles. Few oocytes are attached to the follicle wall by slender stalk. Majority of the oocytes are free (Bar = 100 μm)

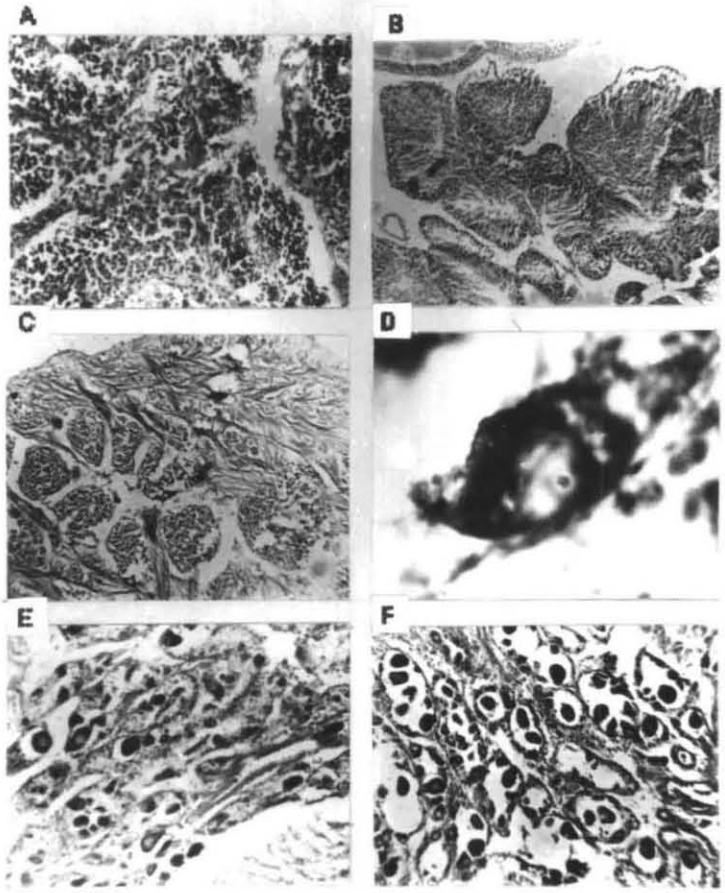
C. Magnified ripe oocyte. Nucleus and nucleolus are visible (Bar = 10 μm)

D. Stage III. Cross section of post-spawned ovary with unspawned oocytes (Bar = 80 μm)

E. Stage IV. Cross section of spent ovary with some relict ova. Follicles contracted. Follicle wall ruptured (Bar = 80 μm)

F. Stage IV. Cross section of spent ovary with cytolysed oocytes (Bar = 80 μm)

Plate 3



Stage V :(Indeterminable/Resting)

The follicles are completely shrunk and collapsed. During this stage, the gonad is quiescent without the trace of any of the germinal cells. The follicles are obliterated and the gonad becomes translucent. Differentiation of sex becomes difficult in this stage (Plate 3).

3.6.3. Sex ratio and size of first maturity :

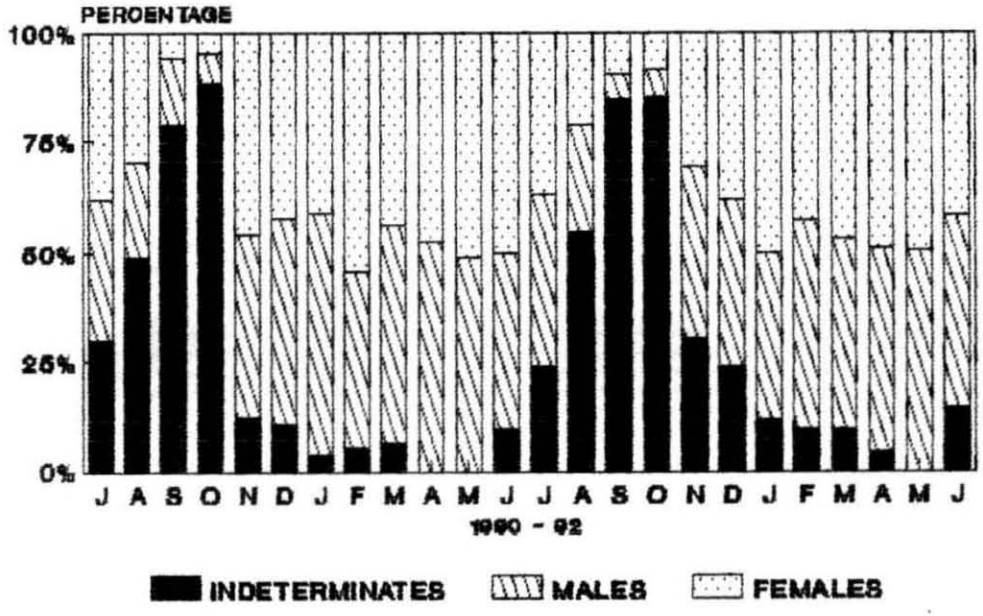
The sex ratio of the population of the clam M. glabratum at the site of study for the period July 1990 to June 1992 is given in Table 12. The total number of clams collected for the growth and gonadial studies was 1663. The size of the clam examined for the gonadial stages ranged from 11.0 mm to 37.0 mm. Of this lot, 425 were immature and hence unsexed. Of the remaining 1238 clams, the male gonads were observed in 451 clams (representing 36.4%), the female gonads in 458 clams (representing 37.0%) and the indeterminable resting gonads in 329 clams (representing 26.6%). During the months when no indeterminable resting gonad occurred, the males and females were represented almost equally (Fig.17).

It was also observed that the clam attains first sexual maturity when they are around 19.5 mm in length and weight around 1.8 g to 2.1g. The shell weight of these clams ranged between 1.3 to 1.5g and the flesh weight from 0.15 to 0.22 gm. The clam can

Fig. 17. Distribution of sex in Mesodesma glabratum in different months during the period July 1990 to June 1992.

SEX-WISE DISTRIBUTION
M.GLABRATUM

Fig.17



develop into either a male or female when they first attain sexual maturity.

3.6.4. Annual reproductive cycle :

The annual reproductive cycle of Mesodesma glabratum was studied for a period of 24 months extending from July 1990 to June 1992. Fortnightly samples were collected and studied for their stages of maturity by microscopic and histological examinations. The total number of clams examined for the annual reproductive study was 1663 (Table 12). The percentage frequency of different stages of gonads in each month is given in Table 13 and Figs. 18 & 19. The stages I A and I B (Table 10) representing the active gametogenesis (maturing stages) are grouped together as stage I. Stage II is the mature (ripe) phase where the gonad has attained the maximum size and the gametes are ready to be discharged. Stage III represents the partially spent phase and the stage IV is the spent phase in which the regression has commenced, but the sexes can be differentiated with the residual gametes still present in the lumen of the follicles. Stage V is the spent resting phase where the sexes are indeterminable. The monthwise percentages of each stage for the entire 24 month period indicates the seasonal changes (Table 13: Figs. 18 & 19). The gonadal stages of males and females was determined and confirmed separately through histological sectioning during different months. (Plates 2 & 3).

Table 12. Distribution of size groups, number and their sex during July 1990 to June 1992.

Year/Month	Size range (mm)	Total number	No. of clams				Percentage of sex		
			Imm	Indt	Male	Female	Indt	Male	Female
1990 Jul	12.5-34.0	67	30	11	12	14	29.7	32.5	37.8
Aug	14.0-35.0	60	23	18	8	11	48.6	21.7	29.7
Sep	15.5-35.0	59	26	26	5	2	78.8	15.2	6.0
Oct	18.0-36.0	60	17	38	3	2	88.4	7.0	4.6
Nov	14.5-37.0	60	12	6	20	22	12.5	41.6	45.8
Dec	17.5-33.0	67	22	5	21	19	11.1	46.7	42.2
1991 Jan	14.5-32.0	50	26	1	13	10	4.2	54.2	41.6
Feb	14.0-35.0	57	20	2	15	20	5.4	40.5	54.1
Mar	11.0-36.5	70	24	3	23	20	6.5	50.0	43.5
Apr	14.0-33.0	59	21	0	20	18	-	52.6	47.1
May	17.0-37.0	59	12	0	23	24	-	48.9	51.1
Jun	18.0-35.0	53	13	4	16	20	10.0	40.0	50.0
Jul	13.5-36.0	58	12	11	18	17	23.9	39.1	37.0
Aug	18.0-37.0	59	6	29	13	11	54.7	24.5	20.8
Sep	14.5-33.0	58	5	45	3	5	84.9	5.7	9.4
Oct	17.0-37.0	99	17	70	5	7	85.4	6.1	8.5
Nov	18.0-35.0	60	14	14	18	14	30.4	39.2	30.4
Dec	12.5-33.0	67	25	10	16	16	23.8	38.1	38.1
1992 Jan	13.5-33.5	92	26	8	25	33	12.1	37.9	50.0
Feb	11.0-34.0	83	22	6	29	26	9.8	47.5	42.7
Mar	12.5-34.5	99	16	8	36	39	9.6	43.4	47.0
Apr	18.0-37.0	98	12	4	40	42	4.7	46.5	48.8
May	17.0-36.0	89	14	0	38	37	-	50.7	49.3
Jun	17.5-35.0	80	10	10	31	29	14.3	44.3	41.4
Total		1663	425	329	451	458	-	-	-

Table 13. Percentage frequency of monthly gonadial stages in Males resting and Females.

Year/Month		Male gonadial stages				Resting stage	Female gonadial stages			
		I	II	III	IV	V	IV	III	II	I
1990	Jul	-	-	12.50	18.75	31.25	18.75	18.75	-	-
	Aug	-	-	3.70	11.11	48.15	22.22	14.82	-	-
	Sep	-	-	-	8.00	88.00	4.00	-	-	-
	Oct	2.50	-	-	2.50	92.50	2.50	-	-	-
	Nov	28.00	8.00	-	-	40.00	-	-	4.0	20.0
	Dec	16.66	33.34	-	-	5.55	-	-	27.78	16.67
1991	Jan	14.30	28.58	10.70	-	3.57	-	10.70	25.00	7.15
	Feb	-	9.37	28.13	6.25	6.25	6.25	31.25	12.50	-
	Mar	-	4.25	23.42	17.00	2.13	14.90	31.92	6.38	-
	Apr	-	2.56	17.95	25.65	-	28.20	20.50	5.14	-
	May	-	-	15.55	51.12	-	22.23	11.10	-	-
	Jun	-	-	8.10	43.25	-	43.25	5.40	-	-
	Jul	-	-	-	41.37	24.15	34.48	-	-	-
	Aug	-	-	-	19.00	58.33	16.67	-	-	-
	Sep	-	-	-	2.78	97.22	-	-	-	-
	Oct	-	-	-	-	96.31	3.70	-	-	-
	Nov	27.27	9.09	-	-	31.82	-	-	4.55	27.27
	Dec	16.67	27.78	11.10	-	-	-	5.56	27.78	11.11
1992	Jan	-	26.66	16.67	-	10.0	-	16.67	30.00	-
	Feb	-	10.70	28.58	7.15	-	10.70	28.57	14.30	-
	Mar	-	8.11	24.32	16.22	-	16.22	24.32	10.81	-
	Apr	-	-	21.44	25.00	-	28.56	25.00	-	-
	May	-	-	21.05	31.58	-	31.58	15.79	-	-
	Jun	-	-	12.00	36.00	-	40.00	12.00	-	-

Stage I: Active/maturing phase; Stage II: Ripe/matured phase; Stage III: Post/Partially spawned p
Stage IV: Spent phase; Stage V: Resting/Indeterminable phase;

Fig. 18. Monthly percentage frequency of Mesodesma glabratum in different phases of the reproductive cycle during the period July 1990 to June 1991.

PERCENTAGE GONADIAL FREQUENCY OF M.GLABRATUM

Fig.18

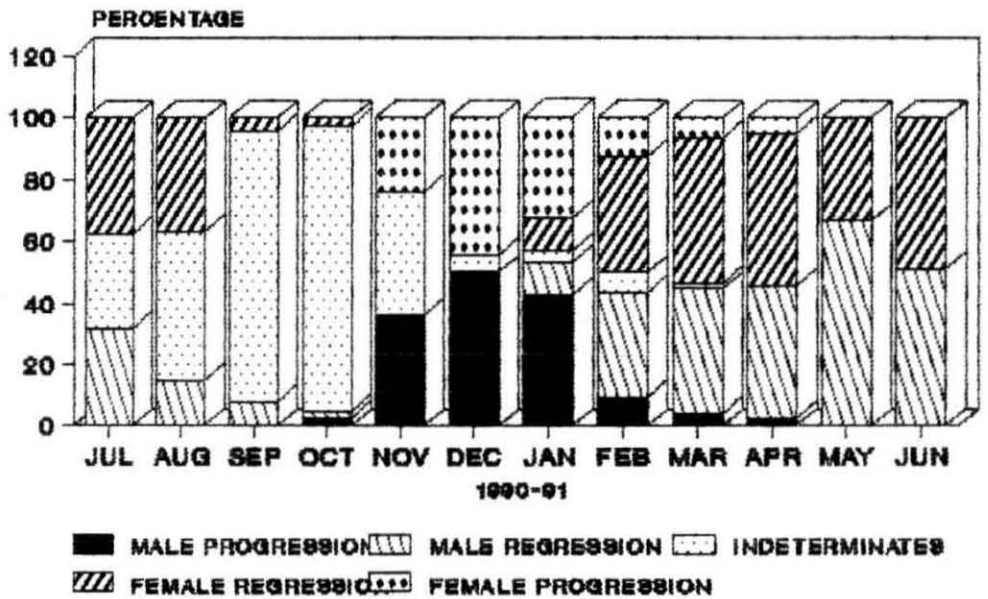
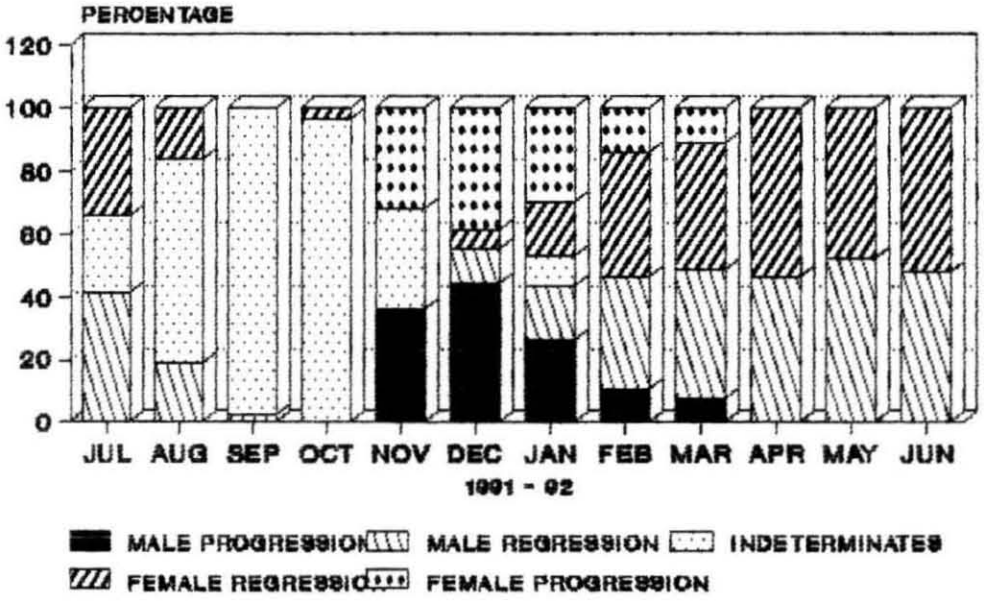


Fig. 19. Monthly percentage frequency of Mesodesma glabratum. in different phases of the reproductive cycle during the period July 1991 to June 1992.

PERCENTAGE GONADIAL FREQUENCY OF M.GLABRATUM

Fig. 19



3.6.4.1. Gonadal condition in Pre-monsoon (July-September) :

July 1990: The gonad was loose and translucent. Most of the gonads of both the sexes were in the spent condition. The percentage frequency of partially spawned phases was 12.50 and 18.75 for males and females respectively; on the other hand in males and females the spent phase was 18.75%. The percentage of indeterminable resting phase was 31.25. The fully spent gonad of males and females were characterised by the presence of negligible number of residual spermatocytes and oocytes and more of vesicular tissue and condensed connective tissue. The follicles were collapsed and the follicular lumen with varied degrees of emptiness. In the spent gonad, the unshed spermatozoa or oocytes in the lumen were in the cytolysed condition.

August : In this month, majority of the clams had entered into the resting indeterminable phase. The percentages of spent males and females together was 33.33 and that of the indeterminable was 48.15. The follicles were completely ruptured leaving a hieroglyphic appearance. In this stage, the gametes which were left as residue in the lumen were undergoing resorption and were covered by connective tissue around the follicles. During the time, the nucleus disappeared, the cytoplasm oozed out, the oocytes were disintegrated and became transparent and thus the contents of the gametes were completely resorbed. When the process of cytolysis and resorption was completed, the follicle

became empty. The gonad became translucent. It was at this stage, the determination of sex of the individual clam was difficult.

September : In September, the percentage frequency of the resting indeterminable gonads was on the increase (88%) when compared to the spent ones which constituted only 12% . Most of the clams did not show any marked variation from those observed in the previous month. The residual gametes in the gonad were completely resorbed and became completely translucent. In some gonads, undifferentiated germ cells began to appear along the lining of the follicular walls.

3.6.4.2. Gonadal condition in Monsoon (October to December):

October : Eventhough the percentage of gonads in the indeterminable resting phase increased further to 92.50%, the gametogenesis had commenced in 2.50% of the male clams. The intensity of activity was considerably low when compared to the peak period of activity. In general, the clams with indeterminable resting gonads did not show any marked difference from those observed in the previous month. In the indeterminable resting gonads, no trace of the follicular tissue was observed and the gonad was completely resorbed.

November : The gametogenic activity initiated during the previous month became intense and, as a result, the percentage of the clams in the active maturing phase increased to 36% in males

and 24% in females. Only 40% of the clams were in the indeterminable resting phase. Due to active gametogenesis, about 22% males and 17% females had entered into the ripe phase.

In the active (maturing) phase, the pronounced enlargement of follicles was due to the rapid increase of their size. In the male gonads, the reproductive follicles contained large number of early spermatogonia with spermatocytes and few spermatids radiating into the lumen of the follicles. The gameotogenic activity in the females proceeded rapidly. The number of follicles in the ovary increased and small oocytes with round distal end protruding into the lumen and the other end attached to the follicular wall by slender stalk. A few follicles were still in the process of proliferation with young oocytes in the follicular wall. In the ripe matured gonads, the gonads were plump and full and formed the major part of the visceral mass. The follicles were enlarged and packed with reproductive elements.

December : As a result of the rapid growth of the follicles in the gonad during the previous month, the gonads were full and plumpy and formed the major part of the viscera. The external appearance of the gonad was flabby and smooth. The percentages of the ripe male and female gonads were 33.34 and 27.78 respectively. About 16.66% of the males and females combinedly entered into the partially spawned phase in the second year of observation.

The follicles in the gonads of males and females were closely packed with ripe gametes without any interspace. The vesicular connective tissue was completely obliterated. The ripe gonads of the males were characterised by streams of spermatozoa, with their tails directed towards the lumen. In the ripe females, the follicles filled the entire gonad area with little interspace in between. Large number of nearly spherical, free oocytes were found in the lumen. They had distinct nucleus and nucleolus.

3.6.4.3. Gonadal condition in Post-monsoon (January-March) :

January 1991 : Majority of the clams still remained in the ripe phase. The percentage of ripe gonads in males was 28.58 and in females it was 25%. The gonads in the partially spawned phase did not show any variation from those observed in the previous month. A mild spawning in December was indicated but the ovary remained in the same condition till the end of January.

February : Spawning had occurred in the clams as evidenced by the presence of large percentage of them in the post or partially spawned phase. The gonads in the ripe phase showed a decrease from the previous month as the spawning had increased. The percentages of partially spawned gonads in males and females were 28.13 and 31.25 respectively.

In the partially or post spawned phase, the gonads gradually became flabby and slightly loose in consistency,

showing a dull creamish colour implying the commencement of spawning. Later on, the follicles shrunk further resulting in the marked reduction in the number of gametes within the lumen. The unspawned oocytes remained attached to the follicular wall but were smaller in size. In some of the follicles of the male gonad, the lumen appeared empty due to the complete discharge of the spermatozoa.

March : The presence of the partially spawned clams was still higher in this month. This showed that the spawning was taking place in this month also. A total of 55.34% of clams were in the partially spawned phase.

3.6.4.4. Gonadal condition in Summer (April-June) :

April : The occurrence of partially spawned clams was still found in fair numbers. However, the higher percentage of spent phase in this month indicated that the spawning activity was still continuing. The percentage of partially spent gonad of 55.34 last month had declined to 38.45. However, the spent phase clams constituting 17% in males and 15% in females during the previous month had increased to 25.65% and 28.20% in males and females respectively.

May : In May, spawning had advanced further and majority of the clams were in the spent phase as indicated by the slow fall of the partially spawned gonads of both the sexes. The combined

percentage of the spent gonads in both sexes was 73.35 and that of the partially spawned ones was only 26.65. The fully spent gonads appeared very loose and transparent. The lumen contained few numbers of residual oocytes and spermatozoa. The follicles were collapsed in some cases, while in others, faint lines indicated the follicular walls. Phagocytes in large numbers appeared both inside and outside the follicles. They cytolysed and devoured the remnants and undischarged residual gametes.

June : Spawning continued further and the number of clams in the spent phase increased . The percentage occurrence of spent gonads of males and females increased and was 86.50. The fully spent gonads were characterised by the presence of a negligible numbers of residual gametes.

A more or less similar pattern of reproductive cycle was observed,during the subsequent year from July 1991 to June 1992 also with minor variations in the time, intensity of gametogenesis and spawning. Between May to July 1991, majority of the gonads were found to remain in spent stage. At the same time, the process of cytolysis and resorption was over in 40% of the gonads. Thereafter, these clams had entered into the indeterminable resting phase. In September and October, the residual reproductive elements were all resorbed and sex of the clam became indeterminable. From November onwards, the gametogenic activity was initiated and the clams entered the

active phase of gonad development. In December and January as a result of the rapid growth of follicles, the gonads attained full maturity to commensurate with the reproductive cycle for the corresponding periods in 1991 and 1992. From February to May, spawning was vigorous as evidenced from the larger presence of larger percentage of partially spawned gonads. By June spent gonad were on the increase owing to the continuation of the spawning activity.

It may be seen from the foregoing account that M. glabratum of the Pandian Thivu follows a more or less definite pattern of annual reproductive cycle with a prolonged breeding period extending from January to July. The gonadal changes were cyclical with well defined phases of gametogenesis such as maturation, ripening, spawning and regression. Gametogenesis or maturation commences between October and November. Ripening takes place mainly in December-January. The spawning activity continues from February to July and enters into the regression or indeterminable resting phase from August-September.

3.6.5. EFFECT OF TEMPERATURE AND SALNITY ON REPRODUCTION :

The temperature and salinity recorded during the study period of two years from July 1990 to June 1992 are given in Table 3. The percentage frequency of the gonadial phases of the clam M. glabratum for the period of study in given in Table 13. The southerly current and the north-east monsoon and to a lesser

extent the south-west monsoon strongly influences the hydrography of the Pandian Thivu waters. Based on the changes observed, each twelve month period from July to the following June is punctuated with 4 distinct periods, viz, premonsoon (July to September), monsoon (October to December), postmonsoon (January to March) and Summer (April to June). The changes in salinity and temperature and their effect on gametogenesis and spawning in the clam Mesodesma glabratum are described below.

3.6.5.1. Premonsoon (July to September) :

As seen in Table 3 and Figs. 5 & 6, the surf water temperature 27 °C in July 1990 had gradually decreased to 26 °C in August and thereafter increased to 28.3 °C in September. Similarly, the interstitial water temperature of 26.7 °C in June decreased to 25.9 °C in July and again increased to 28.2 °C in September. The surf water salinity was high in July (34.08%.) but decreased to 32.93%. in September. Similarly the interstitial water salinity was high in July (33.81%.) but decreased to 32.71%. in September 1990. This same pattern of variations in temperature and salinity was noted in the subsequent year also for the same period.

During July 1990, the percentage of clams with spent gonads was 31.25. In August and September, the clams in their resting indeterminable phase was 48.15% and 88% respectively. An analysis of the data showed that though majority of the clams

entered into the spent phase in July, the conditions of salinity and temperature prevailed in the environment were not congenial for the initiation of gametogenesis.

3.6.5.2. Monsoon (October to December) :

The surf water temperature dropped from 28.7°C in October to 26.2°C in December. Likewise, the interstitial water temperature also decreased from 28.6°C in October to 25.8°C in December 1990. The temperature variation was the same for the period in the subsequent year also. The salinity values of surf water fell from 32.93%. in September to 24.80%. in November 1990. Thereafter, it had increased to 29.15%. in the month of December. A similar decrease was noted in the salinity of the interstitial water also. It had decreased from 32.71%. in September to 27.0%. in November 1990 and again increased to 29.18%. in December 1990. In the subsequent year, the salinity of the surf water had dropped from 32.29%. in September to 23.16%. in December and that of the interstitial water from 32.22%. in September to 22.13% in December.

The percentage occurrence of clams with indeterminable resting gonad in October 1990 was 92.50. Clams with active gametogenesis was only 2.50%. In November, 48% of the clams were in the active phase. In December 61.12% of the clams entered into ripe matured phase.

From the above observations, it is evident that a sudden drop in the temperature from 28.8 °C in October to 26.3 °C in December and a steep fall in the salinity from 32.72‰. in September to 28.8‰. in December acted as a natural stimulus for the initiation of gametogenesis in November and the ripening of the gametes in December. The low values of temperature and salinity obtained during November and December was due mainly to the effect of the north - east monsoon.

3.6.5.3. Post-monsoon (January to March) :

The surf and interstitial water recorded the lowest temperature values of 25.6 °C and 25.5 °C in January 1990. The temperature slowly increased and touched 28.4 °C for the surf water and 27.9 °C for the interstitial water in the month of March 1991. A similar increase was noted for the salinity of the interstitial water from 30.45‰. in January to 32.45‰. in March. The temperature and salinity pattern was the same for the subsequent year also.

In January 1991, 53.58% clams remained in the ripe phase. About 21.4% clams continued to be in the partially spawned condition. But in February, this had increased to 59.38%. In March 55.34% of the clams entered into the partially spawned stage.

Interestingly, the presence of ripe gonads in the clams remained high during December 1991 (61.12%) and January 1992

(50.58%). This has indicated that the clams had to delay their spawning until the temperature and salinity to reach the optimum level. The period of peak spawning in February and March coincided with the increase in temperature and salinity. From this it appears that a rise in salinity and temperature will induce the clams to spawn.

3.6.5.4. Summer (April to June) :

The temperature of the surf water (28.4 °C) in April had a steady increase to 30 °C in May, followed by a decline in June (28.4 °C). Similarly, the temperature of the interstitial water had increased from 27.9 °C in April to 29.5 °C in May and had decreased to 28.3 °C in June. The surf water salinity was low (34.14%.) in April and was slightly increased to 34.87%. in May and a slight decrease was noted in June. The salinity of the interstitial water fluctuated between 33.97%. and 34.26%. during April to June. Majority of the clams were spent. The percentage occurrence of the spent clams in April was 53.85 and had increased to 73.35 in May and 86.50 in June. This indicates that the spawning was continued from April to June when high salinity and temperature conditions prevailed in the environment.

3.7. TISSUE WEIGHT STUDY :

3.7.1. Seasonal changes in tissue weight :

The chemical composition and tissue weight of clams are known to undergo seasonal changes as they pass through various physiological phases due to feeding, maturation, spawning and recovery. In the edible oysters, (*Crassostrea* sp.) changes in the body weight of the tissue various greatly according to the changes in water temperature and currents, food supply, exposure to light, intertidal exposure and many other factors (Medcof, 1955; Qualye, 1969). The changes in the wet and dry weight of the clam are mainly influenced by the salinity of the water. The fluctuations in water content of the tissue are due to the absorption and loss of salts from the body of animals which again contribute to the changes in chemical composition of the clams tissue.

3.7.2. Wet and dry tissue weight :

The changes which had taken place in the body tissues of the clams with regard to wet and dry weights in relation to different maturity condition of the sexes is given in Table 14. The immature clams had more water (81.82%), less dry matter (2.46%) in the flesh whereas the resting indeterminables had less water (71.36%) and more dry matter (3.21%). In males, the water content of the gonad increased from 74.04% in the active maturing gonads to 80.34% in the spent ones. The dry matter of the flesh

Table 14. Sex-wise and maturity-wise mean percentages of variations in shell, wet tissue dry tissue and water content in *M. glabratum*

Sex	Maturity stages	No.of clams	Percentage of Total weight			
			Shell	Tissue		
				wet	dry	Water
Imm	-	40	75.38	13.53	2.64	81.82
Male	I	50	75.66	13.02	3.38	74.04
	II	50	74.94	14.43	2.90	79.90
	III	50	76.02	14.41	3.02	79.04
	IV	50	74.51	14.60	2.87	80.34
Female	I	50	75.18	13.12	3.21	75.53
	II	50	75.37	13.89	3.09	77.75
	III	50	75.15	14.44	2.83	80.40
	IV	50	74.00	15.47	2.90	81.25
Indt	V	60	74.71	11.21	3.21	71.36

Imm: Immature; Indt: Indeterminables; I: Active; II Matured;
III: Partially spawned IV: Spent.

fluctuated between 2.87% to 3.38%. In females, the water content of the gonad tissue increased from 75.53% in the maturing clams to 81.25% in the clams with spent gonads. The dry matter of the flesh ranged between 2.83% to 3.21% of the wet tissue weight. In the case of the percentage wet weight of the tissue on total weight, an increase of 13.02% in the active maturing phase to 14.60% in the spent phase was noted in males. In females also the same trend of increase was noted and it ranged from 13.12% to 15.47% of the total weight. In the immature clams, the wet flesh was 13.53% on total weight and in indeterminables it was 11.21% .

The changes in wet and dry tissue weight as a percentage on the total weight, for the period from July 1990 to June 1991 are summarised in Table 15. The monthly mean percentage wet weight ranged from 10.91 to 15.44 for males 12.08 to 15.27 for females and 14.38 to 14.66 for indeterminables. The monthly mean values of percentage dry weight ranged from 2.23 to 3.29 for males, 2.58 to 3.27 for females and 2.72 to 3.39 for indeterminables. The monthly mean value of percentage wet and dry tissue weight did not differ much between males and females and the trend of fluctuation was similar for both the sexes.

During July 1990 most of the gonads of clams were in the partially and fully spent phase in the reproductive cycle. The monthly mean percentage wet and dry tissue weight was 14.00 wet weight (2.60 dry weight) in males, 13.92 wet weight (2.58 dry

Table 15. Percentage mean monthly variations in the weights of shell, wet tissue, dry tissue and water content in M. glabratum during July 1990 to June 1991.

Year/ month	Sex	No. of clams	Percentages of total weight			
			Shell	Tissue		
				wet	dry	water
1990 Jul	M	10	75.74	14.00	2.60	81.42
	F	12	75.11	13.92	2.58	81.46
	I	12	75.17	13.56	2.97	78.10
Aug	M	10	75.10	14.21	2.52	81.70
	F	10	74.98	14.04	2.67	80.98
	I	10	74.82	13.87	3.04	78.08
Sep	M	15	74.25	14.31	2.85	80.08
	F	13	74.18	13.78	3.03	78.01
	I	12	74.10	13.97	3.27	76.59
Oct	M	15	74.21	14.28	2.85	80.04
	F	10	74.21	13.44	2.94	78.13
	I	10	74.14	13.76	3.08	77.62
Nov	M	12	74.37	10.91	2.26	79.29
	F	10	74.08	12.08	2.94	75.66
	I	8	74.53	11.38	2.72	76.10
Dec	M	15	76.80	14.00	3.25	76.77
	F	15	76.22	14.51	3.18	78.08
	I	-	-	-	-	-
1991 Jan	M	12	76.24	13.92	3.29	76.36
	F	12	75.76	14.08	3.20	77.27
	I	8	75.39	14.07	3.45	75.48
Feb	M	10	74.52	12.57	3.05	75.74
	F	10	74.41	12.98	3.27	74.81
	I	10	74.38	12.98	3.39	73.88
Mar	M	15	74.91	15.44	3.08	80.05
	F	15	73.55	15.37	3.04	80.22
	I	10	74.01	14.66	3.11	78.79
Apr	M	15	74.95	14.38	2.96	79.42
	F	15	73.76	14.44	3.01	79.16
	I	-	-	-	-	-
May	M	15	74.17	13.46	2.98	77.86
	F	15	73.63	12.84	2.77	78.43
	I	-	-	-	-	-
Jun	M	15	75.00	14.38	3.05	78.79
	F	15	74.43	14.43	3.03	79.00
	I	-	-	-	-	-

weight) in females and 13.56 wet weight (2.97 dry weight) in indeterminables.

In August, September and October, the same trend continued more or less without much fluctuations. In November a decrease in the percentage wet and dry tissue weights was observed. This was 10.91% wet weight (2.26% dry weight) in males, 12.08% wet weight (2.94% dry weight) in females and 11.38% wet weight (2.72% dry weight) in indeterminables. Then on, it increased in values till January 1991, which may be the result of the development and proliferation of gonads and their fullness would have contributed to the increased values.

In February 1991, there was a sudden decline in the values of tissue weight to reach a minimum of 12.57% wet weight (3.05% dry weight) in males,12.95% wet weight (3.27% dry weight) in females and 12.98% wet weight (3.39% dry weight) in indeterminables. The decrease in values may be the result of spawning.

In March 1991 onwards, there was a sudden increase in the values to reach a prespawning maximum of 15.44% wet weight (3.08% dry weight) in males, 15.37% wet weight (3.04% dry weight) in females and 14.66% weight (3.11% dry weight) in indeterminables. The increase in the tissue weight corresponded with the period of rapid development and maturation of the gonads.

The same trend continued in April 1991 also but the tissue weight declined slowly to reach the post spawning minimum of 13.46% wet weight (2.98% dry weight) in males and 12.84% wet weight (2.77% dry weight) in females in May, 1991. The fall in the values was mainly due to the result of spawning.

3.7.1. Water content :

Changes in the percentage water content of the tissues are given in Table 15. In July 1990, the water content of the tissues was 81.42% in males, 81.46% in females and 78.10% in indeterminables. The water content gradually decreased to reach the lowest level of 79.29% in males, 75.66% in females and 76.10% in indeterminables in November 1991. This continued in December 1991 also. The minimum level of water in the tissues was associated with the maturation of gonads.

From January 1991 onwards, the level of water in the tissue increased steadily and reached the post spawning maximum in March and April 1991 of 80.05% in males, 80.22% in females and 78.79% in indeterminables. The increase of water content in the tissue was closely related to the spawning. In general there was a relationship existed between body weight and percentage water content.

From April 1991 onwards, the water level in the tissues gradually dropped to a minimum in May 1991 (77.86 % in males and 78.43% in females). From June onwards the percentage water

content in the body tissue increased and was 78.79% in males and 79.00% in females.

3.8. SEASONAL CHANGES IN THE BIOCHEMICAL COMPOSITION :

Generally, the molluscan organ system is difficult to separate from each other for biochemical analysis. In M. glabratum the wet tissues mainly consists of the foot muscle, hepatopancreas, mantle and the gonadal tissues. As the previous molluscan workers have suggested fluctuations in the organic components in the muscle and hepatopancreas and correlated to changes in the gonadal activity, it was thought worthwhile to make such organ-wise analysis of the organ components.

In the present study the changes in the biochemical composition of the whole body tissues and three components of the body tissues, viz, gonad, hepatopancreas and foot muscle separately of M. glabratum with particular reference to the sex and gonadal maturation, was studied (Table 16: Figs.20 & 21).

3.8.1. Total protein :

The values of the total protein is expressed as mg/10 mg dry weight. The protein level in the whole body tissue of M. glabratum lied between the ranges of 6.3432 mg (spent) to 7.1266 mg for (matured) males and 6.2165 mg (spent) to 6.8340 mg for (matured) females. For the indeterminables, it was 6.5557 mg (Tables 16 & 17).

Table 16. Quantitative analysis of biochemical constituents of whole body tissue of M. glabratum during different stages of maturities (Mean value - expressed in mg/10 mg dry tissue weight.

Biochemical constituent	Maturity stages								
	I		II		III		IV		V
	Male	Female	Male	Female	Male	Female	Male	Female	
Protein	6.6570	6.4872	7.1266	6.8340	6.6768	6.5440	6.3432	6.2165	6.555
Carbohydrate	0.8447	0.9643	0.6324	0.3427	0.8229	0.8933	0.7778	0.8681	0.766
Lipid	0.8950	1.1196	0.8014	1.1376	0.7649	0.8660	0.6538	0.7691	0.664
Ash	1.4080	1.3577	1.3609	1.4168	1.5304	1.6016	1.7363	1.8079	1.765

Table 17. Quantitative analysis of mean protein in different parts of M. glabratum (Mean values - expressed in mg/10 mg part).

Part of body	Stage I		Stage II		Stage III		Stage IV		Stage V
	Male	Female	Male	Female	Male	Female	Male	Female	
Gonad	6.7630	6.5459	7.6063	6.8842	6.5459	6.4030	6.1699	6.1198	6.3840
S.D	0.0147	0.0425	0.0790	0.1358	0.0531	0.1238	0.0719	0.1496	0.0823
S.E	0.0066	0.0190	0.0353	0.0607	0.0237	0.0554	0.0322	0.0669	0.0368
Hepato-pancreas	6.4775	6.1045	6.7755	6.7252	6.6225	6.4676	6.2196	6.0466	6.5011
S.D	0.0408	0.0639	0.0984	0.0585	0.1056	0.1376	0.0687	0.0903	0.1126
S.E	0.0182	0.0286	0.0440	0.0262	0.0472	0.0615	0.0307	0.0404	0.0504
Foot muscle	6.7306	6.8112	6.9979	6.8926	6.8621	6.7613	6.6400	6.4831	6.7821
S.D	0.0648	0.0291	0.1022	0.0744	0.0939	0.0966	0.0603	0.1444	0.0875
S.E	0.0290	0.0130	0.0457	0.0333	0.0420	0.0432	0.0270	0.0646	0.0391

Fig. 20. Biochemical composition of males of *Mesodesma glabratum*.

BIOCHEMICAL CONSTITUENTS
AT DIFFERENT MATURITY STAGES OF MALES

Fig.20

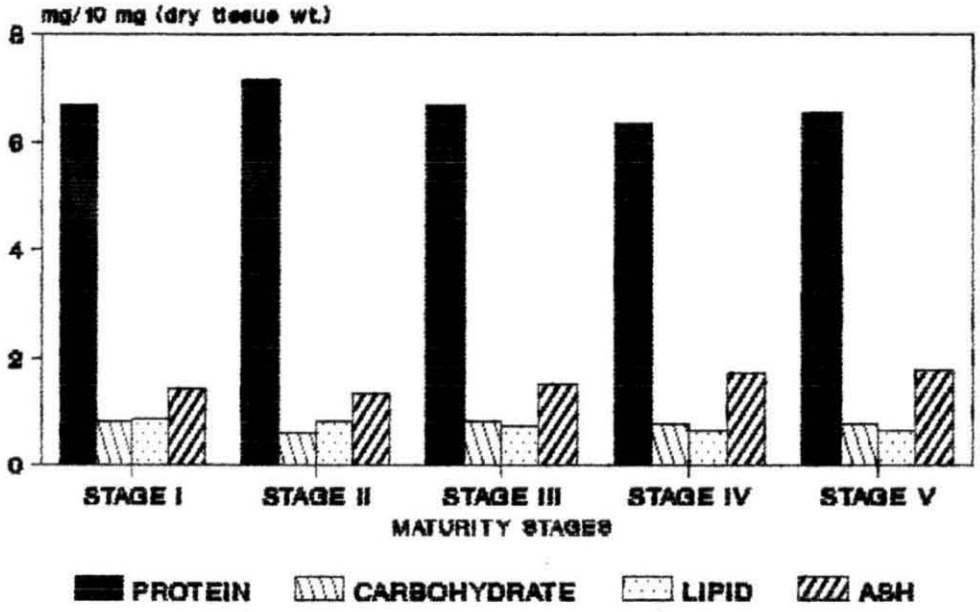
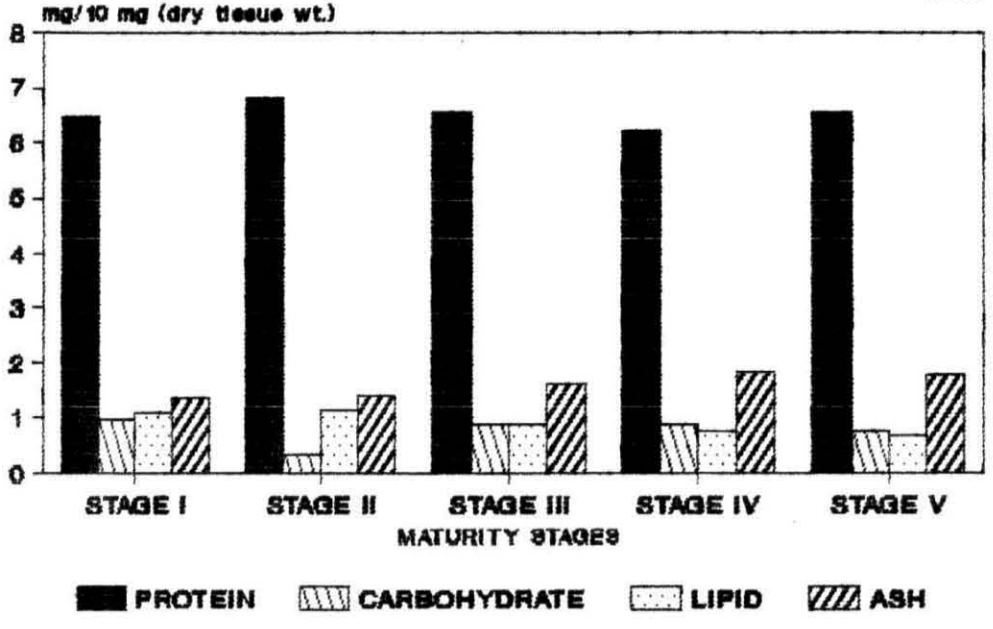


Fig. 21. Biochemical composition of females of Mesodesma glabratum.

BIOCHEMICAL CONSTITUENTS
AT DIFFERENT MATURITY STAGES OF FEMALES

Fig.21



Gonad :

The mean values of protein level in male gonads varied between 6.1198 mg (spent) to 7.6063 mg (matured). In the females, the protein varied between 6.1198 mg to 6.8842 mg for the same stages whereas in the resting (indeterminables) it was 6.3840 mg.

Hepatopancreas :

The mean level of protein in the hepatopancreas of the males varied only slightly between 6.2196 mg (spent) to 6.7755 mg (matured). The same trend of change was noted for the females also, where it ranged between 6.0466 mg and 6.7252 mg. In the indeterminables, it was 6.5011 mg.

Foot muscle :

The protein level in the male foot muscle ranged between 6.6400 mg to 6.9979 mg, in females it ranged from 6.483/mg to 6.8926 mg and in the indeterminables, it was 6.7821 mg.

3.8.2. Carbohydrate :

The carbohydrate level of the whole body tissue varied between 0.6324 mg (matured) to 0.8447 mg (active) in males, 0.3427 mg to 0.9643 mg for the same maturity stages for females and 0.766 mg for the indeterminables (Tables 16 & 18).

Table 18. Quantitative analysis of carbohydrate in different parts of *M. glabratum* (Mean values - expressed in mg/10 mg part).

Part of body	Stage I		Stage II		Stage III		Stage IV		Stage V
	Male	Female	Male	Female	Male	Female	Male	Female	
Gonad	0.9706	1.0566	0.4946	0.3970	0.9551	0.9349	0.8731	0.8908	0.6916
S.D	0.0065	0.0303	0.0053	0.0022	0.0601	0.0122	0.0677	0.0839	0.0084
S.E	0.0029	0.0135	0.0024	0.0010	0.0269	0.0055	0.0303	0.0375	0.0038
Hepato-pancreas	0.7639	0.9059	0.7456	0.0677	0.0719	0.8640	0.7085	0.8508	0.8211
S.D	0.0059	0.0571	0.0581	0.0063	0.0575	0.0141	0.0700	0.0525	0.0070
S.E	0.0026	0.0255	0.0260	0.0028	0.0257	0.0235	0.0313	0.0235	0.0034
Foot muscle	0.7997	0.9356	0.6570	0.5634	0.7716	0.8810	0.7519	0.8628	0.7865
S.D	0.0100	0.0249	0.0091	0.0062	0.0100	0.0137	0.0863	0.0632	0.0111
S.E	0.0045	0.0114	0.0041	0.0028	0.0045	0.0061	0.0386	0.0282	0.0049

Gonad :

In males, the carbohydrate level was the minimum in the matured gonad (0.4946 mg) and maximum in the active phase (0.9760 mg). In females also the same trend of carbohydrate level in the gonad was noticed and it ranged between 0.3979 mg and 1.0066 mg whereas it was 0.6916 mg in the indeterminable gonads.

Hepatopancreas :

The level of carbohydrate did show only slight variations in the hepatopancreas in males during different stages of maturity. It ranged between 0.7085 mg in the spent stage to 0.7639 mg in the active gonadial growth phase. In females, the level of carbohydrate showed much variation between 0.0677 mg in matured clams to 0.9058 mg in clams with active gonad development whereas in indeterminables it was 0.8211 mg.

Foot muscle :

In the foot muscles of male clams, the carbohydrate level varied between 0.6570 mg in the matured ones to 0.7997 mg in the active ones. The level of carbohydrate was high in the females when compared to the males and it ranged between 0.5634 mg to 0.9356 mg for the same stage. In indeterminables, the carbohydrate in the foot muscle was 0.7865 mg.

3.8.3. Lipid :

The lipid level of the whole body tissue in males ranged between 0.6538 mg (spent) to 0.8950 mg in clams with

maturing (active) gonad. The lipid level of the female clams was always slightly higher than the males and it ranged between 0.7691 mg in clams with spent gonads and 1.1376 mg in clams with matured gonads. In the indeterminable resting clams, the lipid level was 0.6647 mg (Tables 16 & 19).

Gonad :

The level of lipid in male gonads was minimum (0.6040 mg) in the spent stage but was high (0.7372 mg) in active maturing phase. But in females,the lipid level increased from 1.0516 mg in the active maturing phase to 1.4192 mg in the ripe phase but afterwards, it decreased to 0.8001 mg in the spent phase. In the resting indeterminable phase the lipid level was low (0.6074 mg).

Hepatopancreas :

The level of lipid in hepatopancreas ranged between 0.7274 mg in the spent phase to 1.0909 mg in the active maturing phase in males. The same trend was noted in the females also. It was 0.8566 mg in the resting phase and 1.3553 mg in the active phase. In the indeterminables, the lipid level was 0.7528 mg.

Foot muscle :

In foot muscle, the lipid level ranged between 0.6301 mg in the spent phase to 0.8568 mg in the active phase in males whereas in females it was 0.6505 mg in the spent phase and 0.9518

Table 19. Quantitative analysis of lipid in different parts of M. glabratum (Mean values - expressed in mg/10 mg part).

Part of body	Stage I		Stage II		Stage III		Stage IV		Stage V
	Male	Female	Male	Female	Male	Female	Male	Female	
Gonad	0.7372	1.0516	0.6598	1.4192	0.6454	0.9129	0.6040	0.8001	0.6074
S.D	0.0250	0.0665	0.0201	0.0856	0.0249	0.0688	0.0069	0.0748	0.0069
S.E	0.0112	0.0297	0.0090	0.0383	0.0111	0.0308	0.0031	0.0335	0.0031
Hepato-pancreas	1.0909	1.3553	0.9117	1.0058	0.8813	0.9529	0.7274	0.8566	0.8528
S.D	0.0062	0.0094	0.0088	0.0152	0.0157	0.0041	0.0025	0.0159	0.0207
S.E	0.0028	0.0042	0.0039	0.0068	0.0070	0.0197	0.0011	0.0071	0.0093
Foot muscle	0.8568	0.9518	0.8330	0.9877	0.7680	0.7322	0.6301	0.6505	0.6338
S.D	0.0619	0.0193	0.1104	0.0517	0.0086	0.0131	0.0165	0.0303	0.0291
S.E	0.0277	0.0086	0.0494	0.0231	0.0038	0.0059	0.0074	0.0136	0.0130

mg in the active phase. In indeterminables, the lipid content in the foot muscle was 0.6338 mg.

3.8.4. Ash :

The values of total ash is expressed as mg/100 mg dry weight. The ash content of the total body tissue varied between 1.3609 mg to 1.7363 mg and 1.3577 mg to 1.7363 mg in males and females respectively. The ash content was low in ripe male clams and high in the spent ones whereas in females, the active maturing clams contained less ash in the body tissue and was high in the spent females. The ash content was 1.7650 mg in the resting indeterminables (Tables 16 & 20).

Gonad :

The ash content of the male gonads ranged between 1.2345 mg in ripe gonads to 1.7198 mg in the spent gonads whereas it was between 1.2752 mg and 1.7555 mg for the same phases in females and 2.0258 mg in the indeterminables.

Hepatopancreas :

In hepatopancreas, the ash content in male was low (1.4747 mg) in the active gonad development phase, increased through the gonad development and was high in the spent clams (1.8339 mg). The same trend was followed in females also and it was 1.5057 mg in the active phase and 1.8535 mg in the spent phase whereas in indeterminables, the ash content in the pancreas was 1.7504 mg.

Table 20. Quantitative analysis of ash in different parts of *M. glabratum* (Mean values - expressed in mg/10 mg part).

Part of body	Stage I		Stage II		Stage III		Stage IV		Stage V
	Male	Female	Male	Female	Male	Female	Male	Female	
Gonad	1.4403	1.3299	1.2345	1.2752	1.4449	1.5249	1.7198	1.7555	2.0258
S.D	0.0100	0.0765	0.0667	0.1411	0.0321	0.0569	0.0365	0.0264	0.0402
S.E	0.0045	0.0342	0.0298	0.0631	0.0143	0.0254	0.0163	0.0565	0.0180
Hepato-pancreas	1.4747	1.5057	1.5264	1.5731	1.6590	1.7053	1.8339	1.8535	1.7504
S.D	0.0375	0.0128	0.0802	0.0459	0.0803	0.1131	0.1048	0.0605	0.0799
S.E	0.0168	0.0057	0.0359	0.0205	0.0359	0.0506	0.0469	0.0271	0.0358
Foot muscle	1.3090	1.2374	1.3217	1.4020	1.4873	1.5747	1.6552	1.8148	1.5188
S.D	0.0239	0.0174	0.0466	0.0398	0.0907	0.0714	0.1103	0.1046	0.0629
S.E	0.0107	0.0078	0.0208	0.0178	0.0405	0.0319	0.0493	0.0468	0.0291

Foot muscle :

The ash content in the foot muscle was in the minimum in the gonad developmental phase in males (1.3090 mg) and increased gradually and reached a level of 1.6552 mg in the spent clams. The same trend was noted in the female clams also. It was 1.2374 mg in the stage I and 1.8148 mg in stage IV. In the resting gonad, the ash content in the foot muscle was 1.5188 mg.

In general, it was noticed that the biochemical constituents of the body tissues of the clams showed differences in their gonad developmental/regression phases. The protein level was the lowest (6.2799 mg) when the clams were spent and gradually accumulated and increased as they were indeterminables and attained the maximum level of 6.9803 mg when they were fully matured and ripe. The carbohydrate constituent of the body tissue was at the maximum level (0.9045 mg) when the clams were in their gametogenic phase but was low (0.4855 mg) when they were in the fully ripe condition. In the case of lipids, the highest level (1.0073 mg) was noticed when the gametogenesis was going on and was in the lowest level (0.6647mg) when they were resting and indeterminables. The ash content also showed a similar trend of increase from the gametogenic phase (1.3829 mg) to spent phase (1.7721 mg). Then it slightly decreased to 1.7650 mg in the resting and indeterminable clams (Table 16 & 20).

3.8.5. Calorific content :

The calorific values are expressed in K cal/g dry weight. The calculated calorific value in total body components varied from 4.368 K cal/g to 5.092 K cal/g in males; 4.477 K cal/g to 5.363 K cal/g in females and 4.439 K cal/g to 4.857 K cal/g in determinables.

The annual mean values of the calorific content of the body tissues of M. glabratum is given in Table 21. In male gonad the calorific value was 4.6659 (± 0.1262) and in female gonad, it was 4.8594 (± 0.1446). The calorific content of the gonads of males and females showed variations. The value was high when the gonads were in the fully ripe condition and was the lowest when the gonads were empty and undergoing resting phase.

The calorific value in the hepatopancreas of male clams was 4.7345 (± 0.1134) and that of females was 4.7989 (± 0.0878). In the case of the clams with resting gonads the annual mean calorific value of the hepatopancreas was 4.7553 (± 0.5695). The calorific value of the hepatopancreas of males and females fluctuated seasonally. As in the case of gonads, here also the value was high in clams with ripe gonads and low when they were with resting gonads.

In the foot mussels, the value to the calorific content did not show much variations in the annual mean values, among the sexes. The values showed fluctuations during seasons of sexual

Table 21. Annual mean calorific values of body tissue of M.glabratum (values expressed as K cal/g dry weight)

Sex	Calorific value K cal/g dry wt. in part of body		
	Gonad	Hepatopancreas	Foot muscle
Male	4.6659 (± 0.1262)	4.7345 (± 0.1134)	4.8188 (± 0.0807)
Female	4.8594 (± 0.1446)	4.7989 (± 0.0878)	4.8249 (± 0.0820)
Ideterminable	-	4.7553 (± 0.5695)	4.8264 (± 0.0436)

maturities and regression both in males and females. High values were obtained in the fully ripe male and females and low values in the resting clams. The annual mean values of the calorific content in the foot muscles of males, females and indeterminables were 4.8188 (± 0.0807), 4.8249 (± 0820) and 4.8264 (± 0.0436).

From the preceeding section, it is evident that there is some accumulation of biochemical components not only in gonad but also in other tissues like hepatopancreas and foot muscle during seasons of gonadial activity. The general decline in these substances during the spawning and post spawning seasons suggests that these body reserves are mobilized and utilized for gametogenic activities. To elucidate further on the role of extra-ovarian organs in contributing to oocyte maturation, biochemical analysis of ovary hepatopancreas and foot muscle has been done on males and females during different maturity conditions. This study showed that the fully ripe gonads generally contained high concentrations of these organic substances. The fluctuations and changes in other tissues like hepatopancreas and foot muscles was related to the changes in the gonad tissue.

DISCUSSION

DISCUSSION

The present investigation undertaken with the main objective of correlating the environmental conditions with the growth and reproductive patterns of the wedge clam, Mesodesma glabratum has provided many interesting results. The distribution is mainly in the mid water mark of the intertidal zone. The beach is some what steep and the intertidal expanse is not very wide. The density of the clam population varied from month to month. The highest number is 74 per sq meterand 190 per linear meter. A similar observation in the Mandapam area in the south east coast of India by Nayar (1955) showed a population density of 475 Donax cuneatus per sq foot area of the beach.

Although the adult population dominated in the mid-water mark, the young ones are mostly found above this mark. The occurrence of the young individuals near the upper water mark is to escape the intensity of the pounding waves on the beach. However, the present observation indicates that, as the young clams grow bigger they merge with the main population, thus making a single zone in the mid-water mark.

Several authors have suggested that the tidal migration of the wedge clam, like the Donax spp. is to get optimum condition for normal life activities (Stoll, 1937, 1938; Mori,

1938, 1950; Jacobson, 1955; Turner and Belding, 1957; Aldrich, 1959; Edgren, 1959; Wade, 1964, 1967; Ansell and Trevallion, 1969; Tiffany, 1971; Truemen, 1971; McLachlan et al., 1979 and Mikkelsen, 1981). But in the present observation on the wedge clam M. glabratum the migration during the high tide and low tide is not clearly understood. Mikkelson (1981) also has not to observe such tidal migration in D. variabilis from Sanibal Island, on the west coast of Florida. It was also found that different species, when present together, may be physically separated in their vertical distribution, because their response differs to the changing physical characteristics of the beach during the tidal cycle. Ansell et al., (1972). found that the population of D. cuneatus and D. spiculum occurring together on the two beaches at Shertalli and Cochin in the west coast of India to exhibit differences in their vertical distribution.

Many benthic invertebrates with a relatively sedentary adult life disperse themselves and colonise new areas through the dispersive larval stages (Jablonski and Lutz, 1983). The wedge clam Mesodesma, like other semi-sedentary invertebrates, colonises new habitat and restocks the existing population by larval disbursion through water currents. The planktonic larval period of most of the tropical clams is about 7 to 21 days (Frenkiel and Moueza, 1980). During this period they may be carried away by the surface currents to far away places. In the south coast, the velocity of the water current varies from 1.13

knots/day to 17 knots/day (The data was obtained from the Tuticorin Port Trust). The surface currents along the east coast is north to south during November and December, and from south to north during February to May (Easterson and Mahadevan, 1980) which coincides with the spawning season of the clams. Therefore, it is reasonable to assume that the young clams which settle on a beach need not be from the same parental stock. Mass spawning and the resultant larvae in the population of one area may be easily carried away to another area by these currents. That may be one of the reasons for the wide annual fluctuation in the recruitment of M. glabratum in the beach.

After settling as a young juvenile (spat), many environmental factors may influence the growing population. Essentially, the factors like slope of the beach, sand grain size and wave action are important. The slope of the beach is decided by the wave action which in turn is responsible for the distribution of different grades of sand on the entire expanse of the beach. Generally, the coarser sands tend to produce steeper beaches and fine sands, a shallow ones, Conversely, the coarser sand particles and comparatively steep beach at the Pandian island supports only a sparse population of the wedge clam M. glabratum when compared to the population of Donax sp in other beaches in the east coast.

Environmental factors like temperature and change of salinity and availability of food material may also be responsible for the growth and attainment of sexual maturity in the clams. Therefore, the successful recruitment and growth of the clams in the beach depends much on the local environmental variables only. Wade (1967) suggested that the food availability in the surf water is the main factor responsible for the differential growth rate among the clam populations. Observations by Ansell et al. (1972) supports this through his study on D. cuneatus from west coast of India.

Donacids are suspension feeders and whenever the clams are covered by water, they suck in water and subsist mainly on particles of organic matter in suspension. These include small diatoms, dinoflagellates, bacteria, minute ova and spermatozoa of invertebrates and a large amount of organic froth derived from the breakdown of plankton or through the degradation of animals, mainly higher in the food chain (Coe, 1948).

In the present study, the organic carbon content of the sand was determined in order to see whether they have any bearing on the growth rate. The organic carbon content of the sand fluctuated between 360 and 750 ug/g. The organic particles are lighter than the sand particles and therefore most of them can settle down only in quiet water. According to Nair and Thampy (1980) there is an inverse relationship between the organic

carbon content of the beach and the turbulence of the overlying water (turbulence is due to churning of the sand by the waves). Therefore, it is assumed that the breaking of waves may take in much of the suspended organic matter available in the sand. Typically, in shallower slope of beach less intense wave activity is experienced. Larger waves may suspend more organic matter in the sediments thus yielding more of food to be available in the water column (Personal communication from Mikkelsen, Department of Benthic ecology, Harbour Branch Foundation, Inc. U.S.A).

Peterson (1982) studying the effects of varying density on two suspension feeding bivalves, Protothaca staminea and Chione undatella at individual and population level found that the growth rate was consistently depressed at intra-specific densities. He also found inter-specific effects of density on growth was usually non-significant and were consistently far smaller, as compared to intra-specific effects.

It is inferred from the present study that the intra-specific competition for food is more important than the availability of suspended particles in the medium. It is of interest to note that the food availability as well as the efficiency of feeding in the tropical conditions are almost equable throughout the year. Therefore, the competition of the individuals in a population for the available food resources may be considered as the major factor affecting the growth.

In many invertebrates growth and reproductive processes are inseparable, in as much as the growth activities continue uninterruptedly even after the attainment of sexual maturity. Many invertebrates such as the crustaceans relegate most of the vital reproductive processes such as gametogenesis to a period when very little body growth occurs (Adiyodi and Subramoniam, 1983). Such a temporal adjustment of growth and reproductive events are important in view of the derivation of precursor materials for these processes from the common storage organs. In other words, in the contribution to the growth and reproductive activities, there must be a perfect co-ordination for the mobilization of reserves from the storage tissues.

The data obtained on the allometric relationship, as calculated from a variety of parameters such as total weight, length, width, thickness and soft tissue weight of M.glabratum is in agreement with the concept of continuous body growth even after sexual maturity. In several other marine invertebrates, especially decapod crustaceans, the growth rate tends to decline once the sexual maturity is attained (Haley,1969, 1973; Lewis, 1977). However, in the lamellibranch mollusc, the present study indicates that there is no such decline in the growth rate as evidenced from the clear straight line relationship suggesting that the growth is linear. This positive relationship between the growth and reproduction of both males and females signifies the perfect adaptation of these clams to the intertidal strip.

In general, the intertidal fauna of the tropical beaches are endowed with optimum food in the medium. The feeding and energy conversion efficiency are also equable in the tropical forms as optimum temperature conditions prevail all through the year. Ansell et al. (1973) have pointed out that there is a closer balance between the metabolic demand of the animals and food availability from the water throughout the year in the tropical species. Accordingly, the growth goes uninterruptedly, although the total life span of these tropical species may be shorter than that of the temperate species. In addition, energy allocated to sex is not significantly different as the total body composition between the sexes are not significantly different. Evidently, the energy expenditure of gamete formation in both the sexes is similar. In M. glabratum there must be present an efficient metabolic organ to convert the food material into energy continuously for growth and reproductive processes.
In Protothaca staminea, Peterson (1982) also arrived at such a conclusion that there is no differential allocation of energy for the competing process of growth and reproduction, even under changed competitive stress.

In several marine invertebrates, the stage of sexual maturity has been shown to be a function of size (Wenner et al., 1974). In addition, there is an influence of season also on the attainment of sexual maturity. For example, in Emerita asiatica, Subramoniam (1977) has shown that the minimum size of egg-bearing

female varied in different months, suggesting that the environment could influence the stage of sexual maturity. In general, the size of sexual maturity is genetically determined. However, as indicated in the above work, there can be fluctuation in the stage of sexual maturity in different months. This condition indirectly indicates the occurrence of a favourable season for reproduction.

M. glabratum also shows fast body growth in accordance with its primitive mode of feeding as well as the availability of adequate food materials in the environment throughout the year. Furthermore, smear analysis of the gonad shows that the minimum size at sexual maturity for all the population obtained in the month of December, indicates that the environmental condition of the beach in this month are more conducive for the attainment of sexual maturity and thereby starting the reproductive activities of the year. The size at which the clam normally attains sexual maturity is 19 mm.

The maximum number of clams enter into sexual maturity in December. From the length frequency studies it is seen that on the completion of seventh month, a small percentage of clams has grown to a size of 19.5 mm The calculated lengths by the growth equation for a period of seven months are found to be 19.5 mm. Though the size of some of the animals of the population in the month of November was 17.2 mm, these animals did not show sexual

maturity. The implication is that not only the environmental factors but also a certain size and corresponding weight is important for the attainment of sexual maturity.

Although, there is slight variations in size at sexual maturity of the clams, the present study stresses the importance of seasonality in the attainment of sexual maturity (in December) which also has a bearing on the synchronization of the reproductive cycle. The tropical species, as a population, breeds continuously (Giese and pearse,1974) as the environmental condition of the marine invertebrates generally are conducive for reproduction all through the year.

In the Indian coasts, intensities of breeding differ in accordance with south west and north east monsoon (Pillai and Nair, 1971), thus showing distinct peaks in the reproductive cycle. However, M. glabratum exhibits an extended annual breeding cycle, in which the initiation of subsequent gametogenesis does not commence soon after spawning, but begins after a discrete inactive period of 3 months. Interestingly, the time taken for the completion of gametogenesis is shorter than the spawning season. Spawning does not occur in one stroke but intermittently over a long period (Rao, 1967; Mane and Nagabhushanam,1976). This strategy in spawning is helpful in the reduction of intra-individual competition among the young juveniles.

A comparision of data on the reproductive cycle of D. cuneatus inhabiting different beaches on the east and west coast of India reveals difference in their breeding cycle, especially with reference to spawning season. In the west coast, the spawning season of D. cuneatus was extended from October to January (Nagabhushanam and Talikhedkar, 1977) and on the east coast it was from January to April (Nayar, 1955). In the present study the spawning season of M. glabratum is found to extend from January to July. In marine invertebrates release of gametes, fertilization and the time of larval metamorphosis is very important as the embryonic development is accomplished within a very short period to release a planktotrophic larva. Therefore, the survival of larvae depends very much on the environmental conditions available at the time of the spawning. A subtle difference in the spawning season of D. cuneatus in various beaches on the Indian coast lends support to this supposition. An analysis of food preferences for these larvae in different beaches may throw new light on this aspect.

Whereas the causative factor for differential spawning period may be related to larval survival, the environmental factors such as the temperature and salinity may constitute the proximate stimulus for gametogenesis and spawning. In temperate regions many workers have shown a close relationship between fluctuation of the habitat media of marine invertebrates and their gonadal conditions. There, the chief spawning stimulus,

in the case of oysters, is the rise in temperature (Nelson, 1928 a; Galtsoff,1930, 1932 and Losanoff and Davis, 1950).

The low surf water temperature recorded from November 1990 (27.6 °C) to December 1990 (26.2 °C) and November 1991 (27.4 °C) to December 1991 (26.2 °C) coincides with the period of active gamete development and ripening in M. glabratum. During the period of peak spawning, the temperature which triggers spawning, lies between 27.6 °C (February) and 28.2 °C (March) in 1990 and 26.1 °C (February) and 27.5 °C (March) in 1991. The temperature in the preceding month of spawning is observed to be 25.6 °C in January 1990 and 25.5 °C in January 1991. This clearly indicates that a slight fall in the temperature during November and December initiates gamete development and ripening of gonad in M. glabratum. A slight increase in the temperature during February and March induces the clam to spawn and this activity continues upto July. The observations of Nayar (1955), Rao (1967) and Victor and Subramoniam (1987), show that in D. cuneatus spawning takes place when the temperature is on the ascent. Therefore, the temperature appears to be an important factor regulating the gametogenesis and spawning in M. glabratum. However, Nagabhushanam and Talikhedkar (1977) are of the opinion that temperature may not influence the spawning of this clam in the west coast.

Another important variation in the sea, under the influence of monsoon rains, is the salinity. In the present investigation the low surf water salinity recorded at the Pandian island area during October-December coincides with the period of active gonad development and ripening in M. glabratum and a sudden increase in the salinity during February and March triggers the clam to spawn which continues till July. Thus in M . glabratum active gametogenesis takes place in both sexes when the temperature and salinity are low and spawning occurs when the temperature and salinity are high.

As the clams show a distinct but extended reproductive cycle, month-wise observations in the changes of the conditions of the gonads of both sexes at histological and biochemical levels are made in order to follow the precise transition occurring in the gametogenic cycle.

Gametogenic cycle of M. glabratum starts precisely in the month of November and mature oocytes are ready for spawning in December-January. The oocytes that remained after the first spawning are slightly smaller than that of the first batch of oocytes released indicating that there may be slight qualitative differences in the different batches of oocytes during the extended period of spawning.

Biochemical investigation on the ovary and the extra ovarian organs, which are considered to be involved in

contributing to yolk precursors, has been made in several marine invertebrates (Giese, 1969). However, the nature of biochemical relationship between these somatic organs as well as the maturing gonad differs greatly among different phyla. In invertebrates, which lay large number of yolky eggs (e.g. Decapod Crustacea), the fluctuations of organic components in the organs contributing the yolk precursors, are more sharp during ovarian maturity. Furthermore, the seasonally reproducing marine invertebrates, such as those found in the temperate and polar regions, also accumulate a large amount of organic substrates long before the onset of gametogenesis (Giese and Pearse, 1974).

Previous biochemical workers on molluscan reproduction have, however, failed to reveal such a definite relationship with gonad maturation (de Jong-Brink et al., 1983). This may be due to difficulties in the isolation of the tissues for biochemical analysis without much contamination from the adjoining organs. Nevertheless, early studies have indicated seasonal fluctuations in the nutrients of the somatic organs such as hepatopancreas, mantle and adductor muscles during gametogenic cycle.

In the present study, biochemical estimation on the ovary, testis, hepatopancreas and foot muscle have been made in relation to seasonal changes in the gonadal activity as well as the different stages of the maturation of the gonad. Preliminary studies have also been carried out on the seasonal changes in the

water content of the whole body tissues and their changes in the organic composition. Calorific content of the individual body components have been determined in order to see changes, if any, in the energetics of the clams during seasons of intense reproduction, reproductive quiescence as well as gonadal recrudescence. These studies show the important of the involvement of different organ systems in the reproductive process.

All the biochemical components of the ovary and testis show a linear increase during gonad maturation; thereafter, the contents decline precipitously during the spawning and post spawning period indicating that the accumulation of the organic substances is only associated with the gamete maturation. With reference to the individual biochemical composition, protein, in general, is more in the male gonad. This may be due to the synthesis of large quantity of nucleoproteins needed during spermatogenesis (Thompson, 1977 and Shafee, 1981). On the other hand the lipid and the carbohydrate have a relatively greater accumulation in the ovary. The carbohydrate content is high during the initial phase of oogenesis but declines in the later stages. This may be due to either the relative increase of other substances such as lipid and protein during the intense period of vitellogenesis or the carbohydrate might be consumed as energy needed in the yolk protein synthesis that occurs in the later part of the oogenesis. Similarly, in Crassostrea virginica the

carbohydrate level is very high in the immature animal and falls precipitously as gamete maturation advances (Galstoff, 1964).

Essentially, lipid forms the major organic component of the oocytes of M. glabratum This has also been reported to be true for other molluscs (Giese, 1969; Ansell, 1974; Sastry, 1979; Shafee, 1981; Victor and Subramoniam, 1987). Conversely, the lipid content of the male testis is considerably low, although the hepatopancreas and foot muscle of the male clams have considerably high level of lipids.

Although the organic components of the ovary and testis increase during maturation, the analysis of hepatopancreas and foot muscle in the corresponding stages has shown a definite flucutation only in lipids correlated to oocyte maturation. The decline in the lipid level of hepatopancreas and foot muscle in the later stages of oogenesis corresponds to its accumulation and storage as neutral lipid in the ovary. Possibly, the stored neutral lipid in the two organs may be translocated to the ovary after undergoing hydrolysis to form the transportable form of simpler lipid units. Such lipid transport from the storage tissues to the gonad has been reported in molluscs (Giese and Pearse, 1974). Carbohydrates being a minor component in ovary and testis, their fluctuation in the hepatopancreas and foot muscle is also not correlated with gonad maturation.

The marine lamellibranch molluscs have an indirect development in that they pass through a planktotrophic larval phase in their early development. In Mesodesma glabratum, like the other wedge clam Donax cuneatus, in 24 hours, the fertilized eggs develop into planktotrophic veliger larvae, namely, the straight-hinge larvae, which start feeding on phytoplankton almost immediately after hatching (Frenkiel and Moueza, 1980). Therefore, a large accumulation of yolk materials is not needed for their abbreviated embryonic development. Instead of that, they produce large numbers of eggs and spawn intermittently in order to compensate the heavy lose which may be incurred between the issuance of gametes and fertilization. This strategy in reproduction (r- K strategy model -Jablonski and Lutz, 1983) is not uncommon among the marine benthic invertebrates (Thorson, 1950; Jablonski and Lutz,1983).

SUMMARY

SUMMARY

1. The wedge clam, Mesodesma glabratum inhabiting the intertidal zone of the Pandian island adjoining Tuticorin are distributed within the mid-intertidal zone. It is non-migratory in nature. The young ones are found to occur in a slightly higher level in the midwater mark.

2. The mean beach slope ranges from 2.0cm/m to 4.0 cm/m. The sand particles are predominantly of 1mm and above in size. The median particle diameter varied from 0.70 to 50.0 mm. The sand organic carbon varied between 360 to 750 ug.

3. The pattern of oscillation of the surf and interstitial water temperature is bimodal with 2 peaks in the month of April - May and October and 2 depressions in the month of August and December - January. The salinity is monocyclic in its annual variation with one peak during south-west monsoon (May-August) and one depression during north-east monsoon (October-January).

4. The allometric relationships between different morphological parameters are found out.

5. The gonad in the active reproductive phase (Stage I) is small inconspicuous and colourless. In the ripe stage (Stage II), the gonad is creamy in colour and is full and plumpy. In the post-spawned phase (Stage III), the gonad

is flabby and loose and grey in colour. In the spent phase (Stage IV), the gonad is shrunken and becomes translucent. Relict oocytes and phagocytes are present in the follicle. In the indeterminable phase (Stage V), the gonad is completely collapsed and the sex can not be differentiated

6. The clam, M. glabratum has a distinct annual reproductive cycle. The gametogenic cycle is at its peak in November-December (monsoon). Spawning commences in February and is extended upto July. After spawning, the next gametogenic activity is initiated after a discrete period of about 3 months.

7. The variations in temperature and salinity have a direct bearing on the spawning of M. glabratum. Active gametogenesis takes place in the month of November when the temperature and salinity are low and spawning occurs in the month of February - March when the temperature and salinity are high.

8. A close relationship has been observed between the wet and dry weight of the tissue and the reproductive cycle of the clam. During active gametogenesis, when the gonad is full, the value of wet and dry flesh weight is high. The spawning of clams results in the corresponding decrease in the flesh weight also.

9. Biochemical constituents such as protein, carbohydrate, lipid and ash in the gonad, hepatopancreas and foot muscle in relation to the seasonal change in the gonadal activity of the male and female clams show a linear increase during gonad maturation and a sharp decline during spawning and post-spawning periods. This indicate that these organic substances are accumulated for utilization in the gamete maturation.

10. The higher protein content in the male gonad may be associated with the synthesis of nucleoprotein in the maturing testis. The carbohydrate is high during the initial phase of oogenesis but decreases in later stages. The fluctuation of this substance in the hepatopancreas and foot muscle is not related to gonad maturation.

11. The ovary contains almost double the quantity of lipids than the testis, reflecting the importance of lipid as an energy source in the eggs. The significant increase in the lipid content in the ovary is associated with the period of vitellogenesis.

12. The calorific values is high in the ripe clams (Stage II) and low in the spent (Stage IV) ones. The gonad, hepatopancreas and foot muscle of female clams have more calorific value than that of the males.

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APPENDIX

APPENDIX

LIST OF PUBLICATIONS

1. **CHELLAM, A.** 1972. Some observations on the Mullets of Vellar Estuary. Dissertation submitted in partial fulfilment for the requirement of the Degree of Master of Science, Annamalai University. 135 pp.

2. **CHELLAM, A.** 1978. Growth of pearl oyster Pinctada fucata in the pearl culture farm at Veppalodai. Indian J. Fish., 25: 77-83.

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13. **CHELLAM, A.**1989. Growth and biometric relationship of pearl oyster Pinctada fucata (Gould). Indian J. Fish., 35(1):1-6.

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15. ALAGARSWAMI, K. AND **A. CHELLAM.** 1977. Change of form and dimensional relationship in the pearl oyster Pinctada fucata from the Gulf of Mannar. Indian J. Fish., 24 (1&2): 1-14.

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27. DHARMARAJ, S. AND **A.CHELLAM**. 1983. Settlement and growth of barnacle and associated fouling organisms in the pearl culture farm in the Gulf of Mannar. Proc. Symp. Coastal Aquaculture, Mar. biol. Ass. India , Pt. 2: 608-613.

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